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Freshwater Wetlands for Wastewater Management Environmental Assessment Handbook

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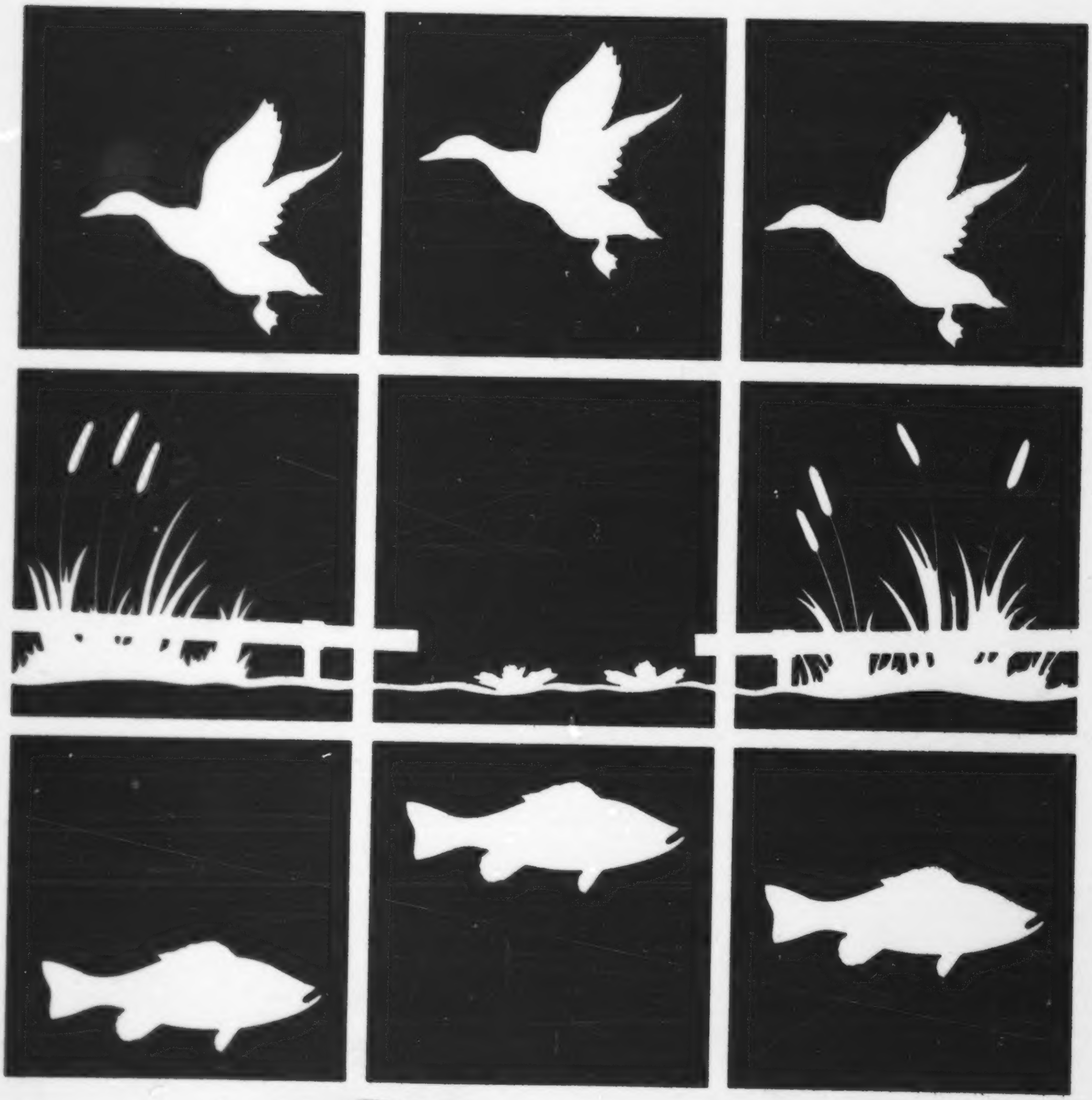

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IV
345 COURTLAND STREET
ATLANTA, GEORGIA 30365

Freshwater Wetlands for Wastewater Management Environmental Assessment Handbook

The Freshwater Wetlands Handbook provides institutional, scientific and engineering guidance for the use of natural, freshwater wetlands for wastewater management. Wetlands have long been recognized for their pollutant removal capabilities and many have been used for wastewater management for some time. Little technical or institutional guidance currently exists for regulating these systems or for planning new systems. This Handbook provides guidance for state and federal regulatory agencies and potential dischargers evaluating wetlands for wastewater disposal or pollutant removal.

Wetlands are also known for their important functions and values in the natural environment. Wetlands provide valuable habitat and food sources for many animal species and perform important hydrologic and pollutant buffering functions. The protection and maintenance of these wetland functions and values are the basis of this guidance.

The Handbook presents a variety of procedures, options and tools that can assist in making wetland wastewater management decisions. As institutional and analytical approaches are refined and as the wetlands wastewater management system data base expands, this Handbook will be updated. Your comments, suggestions and questions on the Handbook are welcome.

Please forward your comments to:

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FRESHWATER WETLANDS FOR WASTEWATER MANAGEMENT
ENVIRONMENTAL ASSESSMENT
HANDBOOK

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EXECUTIVE SUMMARY

1. What is the purpose of this Handbook?

Section 1.1

The Freshwater Wetlands for Wastewater Management Environmental Assessment's purpose is to respond to difficulties encountered by EPA-Region IV's regulatory personnel when evaluating and permitting **domestic wastewater discharges to natural, freshwater wetlands in the Southeast.** This Handbook addresses the institutional, scientific and engineering issues important to the use of wetlands in wastewater management, and it is designed to provide guidance in evaluating wetlands for this purpose. This Handbook is not a statement of policy supporting the use of wetlands for wastewater management under any or all conditions; but it is an acknowledgement that wetlands are currently being used as such by over 400 communities in the Southeast, and for many other communities such use may be a cost-effective wastewater management alternative. The Handbook is a tool by which the planning, implementation and regulation of wetland wastewater management projects in Region IV can be improved.

2. Who should use the Handbook?

Section 1.1

The Handbook provides assistance for a wide range of users, including **state and federal** regulatory and wetland resource personnel, potential **grant applicants** or **permit applicants, environmental and engineering planning** personnel, etc. For ease of use, the Handbook is divided into nine major chapters. Each chapter addresses an important aspect of wetlands-wastewater management issues. As an example, Chapter 3 (Institutional Issues and Procedures) is designed primarily for state/federal regulatory personnel. Chapter 4 (Site Screening and Evaluation) is designed primarily for wetland scientists and engineers assessing the use of a wetland for wastewater management; and Chapters 6 (Engineering Planning and Design) and 7 (Project Implementation) are directed toward engineers involved with planning, designing, constructing and operating wetland wastewater systems.

3. What is a "wetlands discharge"?

The use of natural wetlands in wastewater management involves the discharge of wastewater treated to at least secondary treatment levels (or greater if required to meet water quality standards). Discharge of treated wastewater is then applied via overland flow, single or multiple outfalls, spray irrigation, channel discharge, etc., to a wetland such as a marsh, swamp or bog. Objectives in using a wetland for wastewater management include: (1) **disposal,** in which the wetland is used primarily as a receiving water body to assimilate wastewater; or (2) **treatment and disposal,** in which the wetland is used to improve wastewater quality.

Section 3.1

It is important to note that most wetlands are waters of the U.S. (i.e., wetlands that are adjacent to other waters of the U.S., or wetlands whose use, degradation or destruction of which could affect interstate or foreign commerce), and as such are afforded the protection under the National Pollutant Discharge Elimination System (NPDES) Permit and Water Quality Standards Programs, as are other waters of the U.S.

4. Why use wetlands in wastewater management?

Historically, the use of wetlands in wastewater management in the Southeast occurred because of convenience or the lack of other reasonable alternatives. Only in the past decade have wetland systems incorporated design elements to optimize the wastewater renovation capabilities of wetlands. Currently, the use of wetlands in wastewater management is gaining increased attention for several reasons, such as:

Section 1.3

- An **alternative** for communities with limited surface water discharge opportunities and soils not conducive to land application of wastewater;
- An affordable alternative for communities faced with expensive **advanced treatment** surface water discharge requirements;
- A wastewater management option that could also serve to **restore altered wetlands.**

5. Are there situations in which the use of wetlands should be avoided?

The use of wetlands for wastewater management may not be appropriate in all cases. Most situations will require site-specific analyses to determine site feasibility and acceptability based on wetland types, size, condition and sensitivity. In general terms, the use of wetlands should be avoided when:

Sections 1.3 2.4

- The wetland being considered is a **pristine** wetland and representative of a unique wetland type;
- Projected impacts to the wetland would result in changes that would **threaten the viability** of the system;
- **Conflicts with other uses** could not be adequately mitigated.

6. What laws or regulations apply to the use of wetlands for wastewater management?

Since most wetlands are waters of the U.S., they are regulated primarily under the programs of the **Clean Water Act.** Additionally, other wetland protection programs must be considered when evaluating the use of a wetland. Under the Clean Water Act, the four programs that affect wetland wastewater management decisions are:

- Construction Grants (Section 201)
- Water Quality Standards (Section 303)
- NPDES Permits (Section 402)
- Discharge of Dredge/Fill Permits (Section 404).

Section 3.1

For each program area, there are existing specific program regulations, guidance and procedures; however, the use of wetlands for wastewater management has not been addressed specifically by any program, and clear guidelines do not exist. Minimum criteria relating to waters of the U.S. that can be applied to wetlands discharge require that:

- Water quality standards must be maintained
- A minimum of secondary treatment is required for discharges from municipal treatment facilities to natural wetlands considered to be waters of the U.S.
- An NPDES permit is required for each discharger
- A 404 Permit would be required for the discharge of dredge and fill material into wetlands.

7. How are wetlands different from other waters of the U.S.?

Section 2.3

The regulations for EPA's three major wastewater management programs (Water Quality Standards, NPDES Permit and Construction Grants) are designed for facilities discharging to rivers, streams or other free-flowing surface waters. Wetlands are different from most aquatic systems due to their nature as a **transition between fully terrestrial and fully aquatic systems.** As such, wetlands are often hydrologically slow-moving systems, as opposed to the free-flowing nature of most streams and rivers. Additionally, the functions and uses of wetlands cover a broad range of ecological, water quality and hydrological values. Since the regulatory guidelines and programs developed under the Clean Water Act's wastewater management programs did not acknowledge or address wetland specific considerations, they usually are not applicable to wetlands wastewater management systems.

8. How do Water Quality Standards apply to wetlands and wetlands discharges?

The water quality standards program is co-administered by EPA and each state's water quality agency. Water quality standards serve as the regulatory basis for establishing controls on treatment processes needed to protect established uses. Stream segments are delineated, and associated **use classifications** are established as part of a state's water quality standards program. Numeric and/or narrative **water quality criteria** are established to assure that designated uses will be maintained and protected. Uses and criteria are, therefore, the two components of water quality standards.

Section 3.2

Typically, wetlands in each state fall under the criteria associated with the use classification of the adjacent water body. Wetlands are commonly classified for fish and wildlife uses. As a result, water quality criteria for wetlands based on adjacent water body classifications can be insensitive to inherent differences in wetland types. Establishing new use classifications, wetland subcategories for existing uses or generic or site-specific criteria are alternatives for addressing situations in which established uses and criteria are generally not appropriate for wetlands.

Although wetlands that are waters of the U.S. cannot be classified for "waste transport," they can be used in wastewater management as long as established uses are protected. Many wetland functions and values (e.g., storm buffering, water storage, etc.), however, are not covered by existing use classifications. Additional qualitative or quantitative criteria addressing wetland characteristics (e.g., hydroperiod, water depth, seasonal influences, etc.) may be appropriate to protect wetland uses.

9. How are wetland discharge permits issued under the NPDES Permit Program?

Section 402 of the Clean Water Act authorizes EPA and delegated states to administer the NPDES Permit Program. This program requires a permit for the discharge of pollutants from any point source into waters of the U.S. Where wetlands are waters of the U.S., the discharge of wastewater to the wetland **requires the issuance of an NPDES permit.**

Section 3.3

Important elements of the permitting process include the permit application process, establishing effluent limits, establishing permit conditions and requirements, permit issuance and compliance monitoring. Alternatives contained in the Handbook for application of the NPDES program to wetlands-wastewater systems include the use of a tiered approach for information requests and monitoring requirements based primarily on wetland type and hydraulic loading. The use of performance criteria as a permit requirement to monitor wetland and downstream water quality also is suggested.

10. How are effluent limits for wetland discharges determined?

An important step in establishing effluent limits is determining whether the stream segment (or in this case the wetland) to

Sections

3.3
5.4

which a discharge is proposed is effluent limited (for which technology based limits or secondary treatment is required of municipalities) or water quality limited (for which treatment greater than secondary levels is needed). In water quality-limited situations, the task of establishing effluent limits is not straightforward. The use of water quality models may not adequately predict a wetland's response to a wastewater discharge, and the use of an **on-site wetland assessment** likely will be necessary. The qualitative results of an on-site assessment then need to be related to quantitative or qualitative effluent limits.

On-site assessments should consider geomorphology, soils, hydrology, water quality and ecology as well as the interaction of these components.

11. How does the Construction Grants Program address wetlands discharges?

Section

3.4

EPA is authorized by Section 201 of the Clean Water Act to provide federal grants to eligible municipalities for the planning, design and construction of wastewater facilities. Through the Construction Grants program, a great deal of technical information has been prepared that provides guidelines on various aspects of facilities planning, design and construction. The concept of wastewater management in wetlands is still an emerging wastewater management practice; and, as such, **wetland specific components have not yet been incorporated** into the Construction Grants program guidelines.

When wetlands are being considered for use in wastewater management, the wetlands discharges should be considered as one of several alternatives that could satisfy the wastewater management objectives of a community. Construction grants guidelines addressing wetlands-specific components would, therefore, be helpful for potential wetland dischargers.

12. Are wetland discharge projects fundable under EPA's grants program?

Section

3.4

Funding the purchase of land (or wetlands) through the Construction Grants process depends on the purchase item being an integral part of the treatment process. Since many natural wetlands are waters of the U.S., wastewater discharges to such wetlands may be permitted but are not considered "treatment." The purchase of natural wetlands which are waters of the U.S. to serve as part of the treatment process **cannot be funded** under the grants program **based on current interpretations.**

While in many cases funding for the purchase of a natural wetland may not be grant eligible, demonstrated control or access of the wetland may be a necessary element of the project to assure uninterrupted use of the wetland in wastewater management. Funding decisions related to the treatment facilities or discharge structures would be made as are other non-wetland related funding decisions.

13. How can wetlands be assessed for their use in wastewater management?

Preliminary site screening and detailed site evaluation are two components in assessing wetlands that will determine if a wetland site is appropriate to be used in wastewater management. The site screening/evaluation process depends on the interrelationships of institutional, scientific and engineering considerations. Limitations in any one area can result in a wetlands site being dismissed from further consideration.

Preliminary site screening is a relatively quick and cost-effective procedure for an initial determination of site feasibility. Components of preliminary site screening include wastewater management objectives, wastewater characteristics, wetland type, wetland size and shape, availability and access, environmental condition and sensitivity, and permitting considerations. By examining these components, it will become evident early in the planning process if the wetlands alternative is not feasible. If the site clears preliminary site screening, the wetlands alternative warrants comparison with other potential alternatives.

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4.4

The second level evaluation is detailed site evaluation, in which a wetlands discharge site is assessed fully. In addition to determining the feasibility of using a particular wetlands site, this evaluation provides the basis for engineering design and background information for assessing wetland impacts. Components of this evaluation include: defining wetlands boundaries, determining values and uses, establishing watershed characteristics and connections, assessing water budget and hydroperiod, determining background water quality conditions, assessing wetland vegetation and evaluating soil characteristics. The extent of these analyses varies with the degree of uncertainty associated with a proposed discharge.

As noted in the response to question 9, a tiered approach for information requirements is suggested in this Handbook. Based on the degree of uncertainty and risk associated with a discharge, information requirements vary by hydraulic loading and wetland type. With increased loadings to sensitive wetland types, additional information may be required.

14. Under what circumstances should a discharge to a wetland be disallowed?

By going through preliminary site screening and the detailed site evaluation, conditions will be identified under which a wastewater discharge to a wetland is not recommended. The following conditions may preclude a wetlands discharge:

Section 4.5

- The wastewater contains a significant **industrial component** (e.g., salts, metals, toxics, etc.)
- The wetland type or area to be used is considered **threatened or unique**
- **Threatened or endangered species** are present in the wetland
- A wetland is particularly **sensitive to alterations** due to wastewater discharges (e.g., pH, flow, etc.)
- The **size** of the wetland to be used **is not adequate** to accommodate the proposed volume of wastewater (including projected future flows)
- **Control or ownership** of the wetland is not possible.

In some cases these circumstances can be mitigated, thereby allowing further consideration of the wetlands discharge.

15. What loading criteria or discharge criteria exist for wetlands discharges?

Discharge loading limits for wetlands should be based on the wetland's ability to assimilate wastewater. Loading rates observed from existing wetland studies and ongoing wetland discharges provide guidance on discharge levels that do not appear to degrade wetlands and those that do lead to wetland stress or degradation. Site specific assessments are necessary to determine the applicability of existing knowledge to a particular wetland.

Section 5.3

Observed wastewater loading data can be grouped by wetland types (e.g., bottomland hardwoods, cypress strands, marshes, bogs, pocosins, cypress domes, etc.) for a range of parameters, including hydraulic loading, nutrient loading and organic loading. Additional information on metals, toxins, pathogens and pH levels are also available, but to a lesser extent. Some systems, such as cypress swamps, have been studied quite extensively related to wastewater additions; whereas other systems, such as bogs and bottomland hardwoods, have not been studied to the same extent.

Transfer of knowledge from one wetland type to another is not necessarily valid because wetlands respond differently to wastewater additions. The site-specificity of loading rates is important to wetland wastewater system decisions and modifications based on on-site assessments, pilot studies and system performance are likely to be appropriate.

16. What engineering options apply to wetlands discharge systems?

Proper engineering of wetlands systems and management of system operations can serve to overcome some wastewater management obstacles, mitigate potential adverse impacts and optimize the ability of a wetland to renovate wastewater. Engineering options are available which can assist in meeting water quality objectives of a wetlands alternative. These options are both structural and operational. The wide variety of wetland types requires an evaluation of the site-specific conditions for each wetland-wastewater system to ensure selection of the most appropriate engineering options.

Some of the structural options that are available for use in wetland discharge systems include:

- **Wastewater storage** to allow desired application rates and avoid overloading
- **Flow distribution** mechanisms to assure uniform distribution of wastewater, avoid short circuiting and control discharge velocities
- **Back-up systems** for use during times when wetlands application is limited (winter or wet-weather periods)
- **Water regulation** through the use of berms, dikes or levees to control water flow and flow patterns
- **Disinfection** by chlorination-dechlorination or alternative methods to avoid wetland impacts related to chlorination
- **Facilities installation** techniques to avoid wetland impacts (e.g., above ground piping).

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7.3

Operational options in managing wastewater in wetlands are related to specific system objectives. The protection of wetland uses, optimizing system start-up and maximizing system life are system objectives to be considered. Operational options to help meet these objectives involve:

- **Construction timing** to minimize wetland impacts
- **Quality control** of installation procedures to assure wetland dependent design components are constructed
- **Coordinating start-up** to avoid naturally sensitive periods
- **Start-up procedures** to plan for gradual build-up of flow and optimal discharge schedule and flow pattern
- **Seasonal operation** to avoid or minimize impacts during critical seasons
- **Periodic inspections** in conjunction with a monitoring program.

17. How are constructed wetlands different from natural wetlands?

The focus of this Handbook is the use of natural freshwater wetlands for wastewater management. The concept of artificial or created wetlands merits discussion because some technical information from created wetlands may be applicable, and created wetlands may be a viable alternative for communities that do not have access to a suitable natural wetland.

Section 6.5

Since **wetlands created for wastewater treatment are not waters of the U.S.** (so long as they were not originally created in waters of the U.S.), they are not regulated to the same extent as natural systems. Created wetlands can be used to provide treatment. Additionally, a variety of structural engineering options that would not be appropriate for natural systems are available for created systems (e.g., periodic flushing, harvesting vegetation, installing a liner, recirculating wastewater, etc.). They can also involve the purchase of land which is eligible for Construction Grants funding since the land would serve as an integral part of the treatment system.

With the use of created wetlands in New York, Pennsylvania, Iowa, Nevada, California, and other states, the inventory of design and operating data is increasing; and created wetlands may offer a potential alternative in which the use of natural wetlands is neither possible nor practical.

18. What mitigation practices can be used in a natural wetlands discharge system?

Section 7.4

Wetlands protection should be a prime objective of any wastewater discharge to a natural wetlands and therefore is a fundamental element of the Handbook. The entire Handbook addresses mitigation practices in terms of what can be done to prevent or reduce impacts to wetlands from a wastewater discharge.

The **engineering design options** (e.g., type of discharge structure), **construction practices** (e.g., use of boardwalks) and **O&M procedures** (e.g., discharging following natural hydroperiod) discussed by the Handbook incorporate mitigation concepts. Mitigation is also provided by preliminary and detailed site evaluations based on the protective function afforded by these evaluations through identifying unacceptable sites.

19. What is required for post-discharge monitoring?

All discharges to waters of the U.S. that have an NPDES permit require that effluent quality be monitored. The purposes of effluent quality monitoring are to determine: if permit limits are being attained, if water quality standards criteria are being maintained, if water quality standards uses are being protected and if the established effluent limits are sufficient to allow the maintenance of water quality standards. Monitoring wetland discharges also should be viewed in terms of assessing wetland impacts, long-term viability of the wetland and the response of the wetland to a wastewater discharge.

Section 7.5

Much of the post-discharge monitoring of existing wetland projects has been conducted in conjunction with research projects. These programs do provide an indication of the major parameters and general design of a monitoring program that could be implemented for a wetlands discharge.

Elements of a **post-discharge monitoring program could include**: pollutant assessments, hydrological measurements (water budget, hydroperiod, flow patterns), water quality measurements (basic analyses, elective analyses, water quality assessments) and ecological measurements (vegetation, aquatic and terrestrial fauna, ecological assessments). The level of detail required in a post-discharge monitoring program will be determined by a number of factors, including the background condition of the wetland, the sensitivity of the wetland to discharges, the size of the wetland, the volume of wastewater discharged, etc.

20. What are the risks and uncertainties associated with natural wetland discharges?

Section 8.4

Change is inevitable when wastewater is introduced to a natural wetland. Regardless of how well planned, designed, constructed or managed, some degree of system alteration will occur. The task at hand is to avoid wetlands degradation, protect wetlands uses, and to minimize adverse environmental effects while optimizing use of the wetland for wastewater management. The impacts of wastewater on wetlands are interactive. While the data base for understanding natural systems has increased in recent years, certain data limitations and uncertainties remain. **Uncertainties and risks pertain primarily** to assessing a wetlands assimilative capacity, predicting wetland impacts, establishing effluent limits, determining downstream impacts and evaluating the long-term potential of a wetland receiving wastewater.

21. Who should be contacted for more information on wetland discharges?

Section 9.6

Within EPA, Region IV, the point of contact depends upon the program issue involved. The **NEPA Compliance Section** (404/881-3776) in the Office of Policy and Management has lead responsibility for preparing the Handbook and should be contacted for general procedural and multi-program questions. The Water Quality Section (404/881-3116) in the Water Management Division should be contacted for water quality standards issues. The Permits Section (404/881-3012) in the Water Management Division should be contacted for NPDES permitting questions. The North Area (404/881-2005) and South Area

(404/881-3633) Grants Management Sections in the Water Management Division should be contacted for Construction Grants issues. Other important federal agencies are the U.S. Army Corps of Engineers (COE) and the U.S. Fish and Wildlife Service (FWS). The COE is responsible for construction activities in wetlands and the FWS is responsible for the ecological review of projects receiving federal funds. The FWS can also provide assistance concerning wetlands identification, delineation, mapping and values. State water quality and environmental agencies are important since they typically administer Clean Water Act program.

PREFACE

In 1981 the Environmental Protection Agency (Region IV) initiated an Environmental Assessment on the use of freshwater wetlands for municipal wastewater management. This study primarily grew out of the difficulties being encountered by regulatory personnel in evaluating and permitting discharges to wetlands, a wastewater management alternative receiving increased attention and being practiced on a widescale basis.

The scope of the study focuses on the use of **natural, freshwater wetlands** for wastewater management in the eight Region IV states: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina and Tennessee. Figure 1 depicts the major tasks involved with this study. A separate, companion study (EPA 1984) investigated the use of saltwater wetlands for wastewater management.

The initial phase of the Environmental Assessment included an inventory of existing discharges, wetland types and extent, wetland classification systems, regulatory procedures and policies, wetland functions and values, and engineering considerations associated with wetlands discharges. The inventory phase involved conducting a literature search, sending questionnaires to each identified wetlands discharger in the eight states, reviewing regulations and policies pertaining to wetlands discharges, and contacting numerous regulatory agency personnel. Two review committees provided additional guidance: an Institutional Review Committee (IRC), composed of one state regulatory agency representative from each Region IV state and federal agencies with wetland responsibilities (Corps of Engineers, Fish and Wildlife Service); and a Technical Review Committee (TRC), composed of individuals with direct experience with wetlands or wetlands discharges, primarily individuals from academic institutions involved with wetlands research. The first phase report of the Environmental Assessment was a compilation of material representing the state of current knowledge about wetlands used for wastewater management (EPA 1983).

The second phase of the study involved an analysis of current Clean Water Act regulations that influence wetlands. Practices affecting regulation or the use of wetlands for wastewater management were categorized into the three broad areas of institutional, scientific and engineering issues. Three draft reports summarized this second phase of the Environmental Assessment, which concerned regulatory requirements, their applicability to wetlands and wetlands discharges, and their relationship to current state programs.

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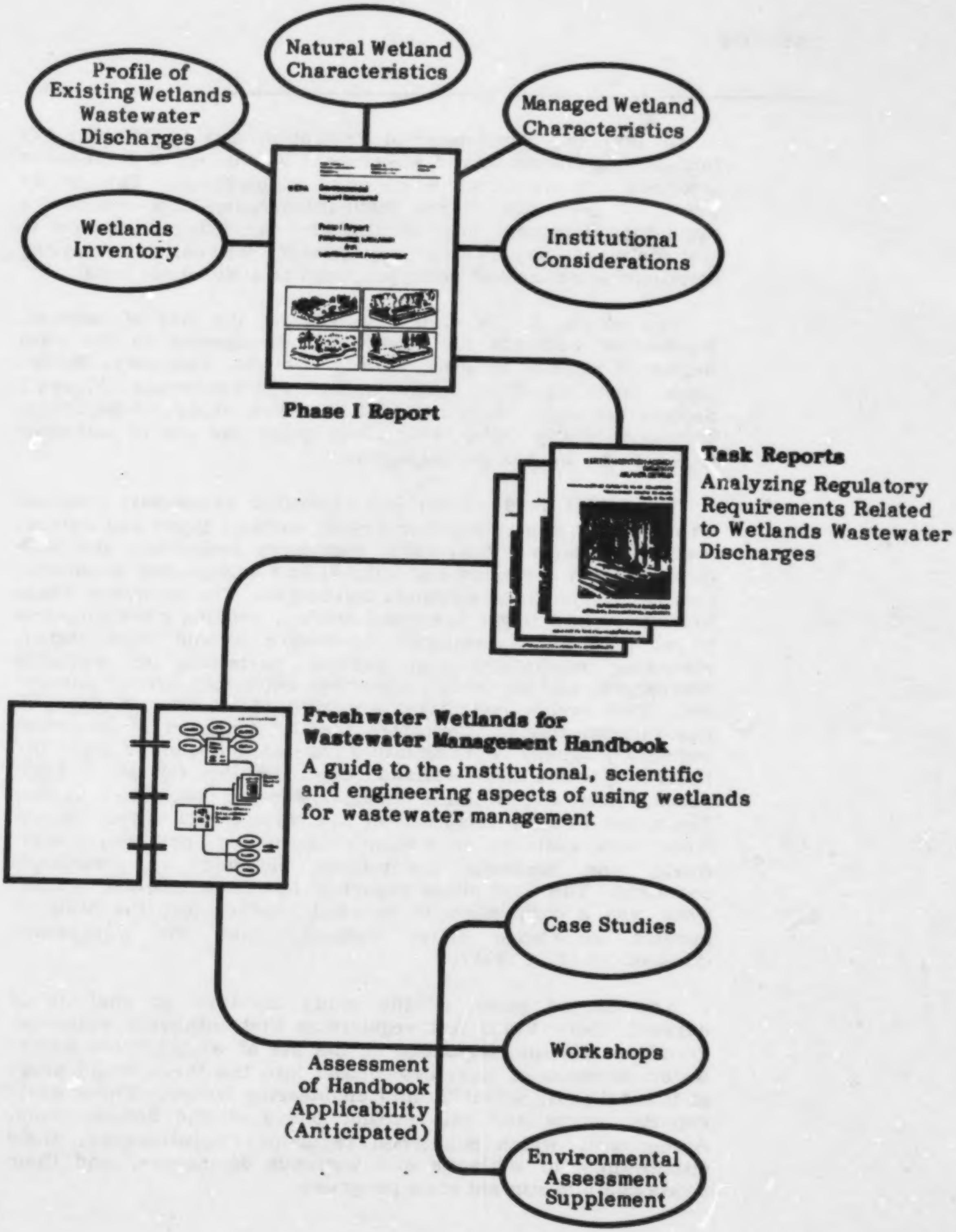
Figure 1. Major Elements of the Freshwater Wetlands for Wastewater Management Environmental Assessment, EPA Region IV.


Profile of Existing Wetlands Wastewater Discharges
Natural Wetland Characteristics
Managed Wetland Characteristics
Wetlands Inventory
Institutional Considerations
Phase I Report
Task Reports
Analyzing Regulatory Requirements Related to Wetlands Wastewater Discharges
Freshwater Wetlands for Wastewater Management Handbook
A guide to the institutional, scientific and engineering aspects of using wetlands for wastewater management
Case Studies
Workshops
Assessment of Handbook Applicability (Anticipated)
Environmental Assessment Supplement

This Handbook represents the culmination of the Environmental Assessment by addressing the relationship between existing regulatory requirements and the institutional, scientific and engineering issues critical to the use of wetlands for wastewater management. However, this document is not a statement of federal or state policy supporting the use of wetlands for wastewater management under any or all conditions. Rather, this document is an acknowledgement that wetlands are being used as such; and, for many communities in the southeast, it may be a cost-effective wastewater management alternative. As major regulatory guidelines are developed and technical information is obtained, Handbook updates will be provided.

1.0 INTRODUCTION

1.1 PURPOSE AND USE OF THE HANDBOOK 1-1

1.2 RELATIONSHIP OF THE HANDBOOK TO WETLAND ISSUES AND REGULATORY PROCEDURES 1-5

1.3 WHY USE WETLANDS IN WASTEWATER MANAGEMENT? 1-7

1.0 INTRODUCTION

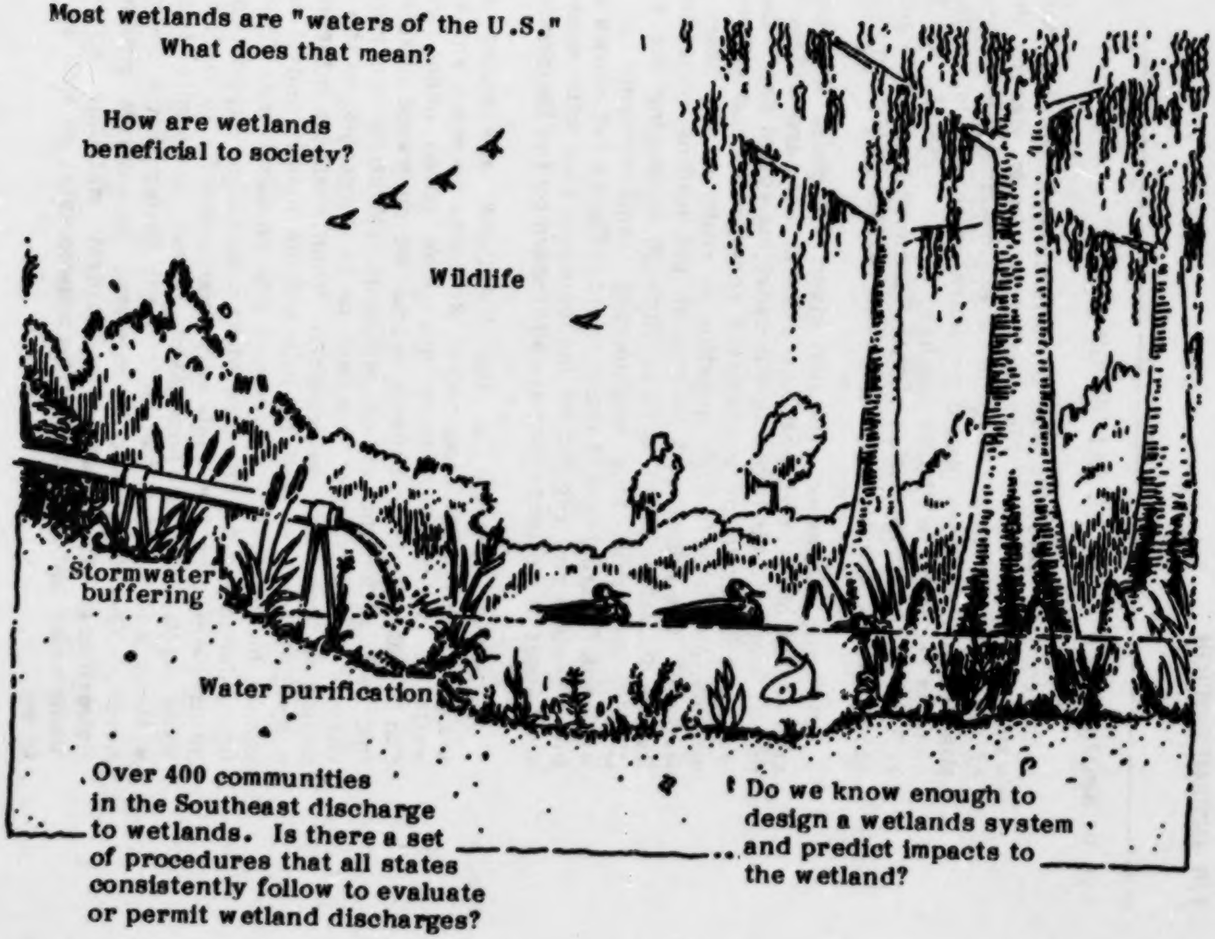
1.1 PURPOSE AND USE OF THE HANDBOOK

In recent years the use of natural wetlands for municipal wastewater management increased dramatically, despite the lack of formal regulatory, scientific or engineering guidelines. The absence of guidelines placed pressure on those who would use, or must regulate, wetlands discharges. As a result, EPA Region IV initiated the compilation of this Handbook to provide guidance to potential wetlands dischargers and regulatory personnel.

With the increased attention given wetlands, the functions and values of natural wetlands systems now are widely recognized; hence, their protection is receiving added emphasis. Can wetlands be used for wastewater management and still be adequately protected? This question is really at the heart of the wetlands use issue and is one of the leading questions this Handbook attempts to answer through examining the institutional, scientific and engineering considerations of using wetlands for wastewater management. Figure 1-1 shows some of the technical and regulatory issues associated with wastewater discharges to wetlands that are addressed by the Handbook.

Technical contents of the Handbook are based on the available information from recent wetlands research and existing wetlands discharges. Some questions posed about wetlands discharges and their impacts cannot be answered absolutely to the satisfaction of either wetlands scientists or regulatory personnel. An attempt has been made to respond to the critical issues as thoroughly as possible. When available information on a specific topic is limited, this will be noted; and if an issue cannot be resolved, the reasons will be discussed. The Handbook should not be interpreted as unqualified support for using natural wetlands for wastewater management. In fact, alternatives such as land application, small community innovative systems and created wetlands might better suit a community's needs. **The Handbook is intended to provide guidance for determining when using a natural wetlands system for wastewater management may be appropriate, as well as when it is not.**

For ease of use, the Handbook is divided into nine major chapters. Beginning each chapter is a section describing how that chapter's contents relate to the decision making process based on current regulations, policies and practices. This should interest potential users, since it provides the rationale behind information or procedural requirements. The User's Guide ending most chapters is designed to lead a potential user


Most wetlands are "waters of the U.S." What does that mean?
How are wetlands beneficial to society?
Wildlife
Stormwater buffering
Water purification
Over 400 communities in the Southeast discharge to wetlands. Is there a set of procedures that all states consistently follow to evaluate or permit wetland discharges?
Do we know enough to design a wetlands system and predict impacts to the wetland?

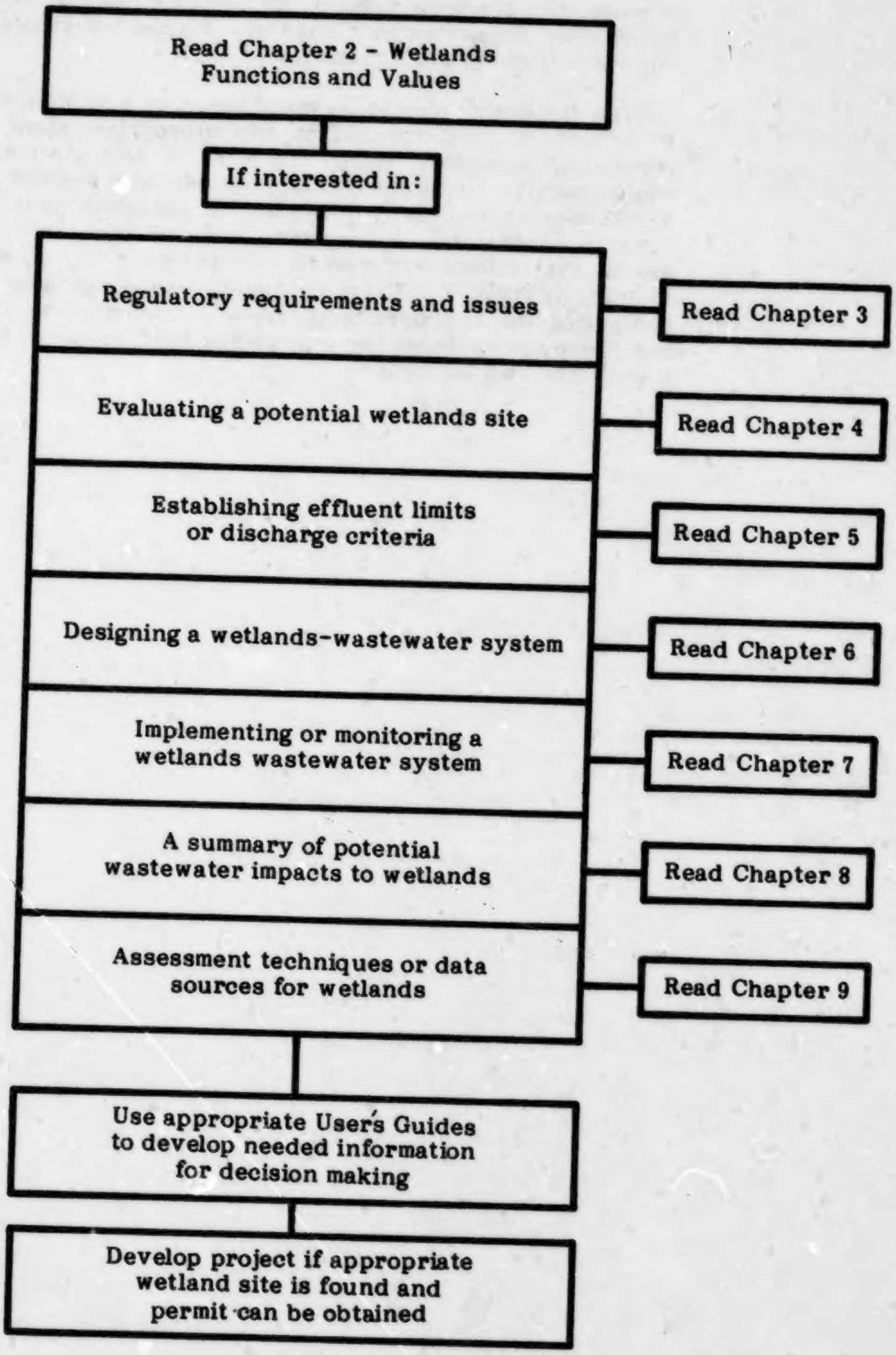
Source: CTA Environmental, Inc. 1985.

Figure. 1-1. Basic Technical and Regulatory Issues Associated with Wastewater Discharges to Wetlands.

through the analyses needed for decision making based on the information presented in a chapter. Figure 1-2 shows a general approach to using the Handbook.

The Handbook should be considered as a guidance document to be used and interpreted by the appropriate state or federal regulatory agencies, rather than as a self-contained list of requirements. Upon considering the use of a wetland as part of a wastewater management system, a potential user should be sure to contact the appropriate agencies (see Section 9.6) to assure that efforts are coordinated and properly directed. Due to the evolution of policies and guidelines concerning wetlands, contacting the appropriate agencies is important to ensure that the proper procedures are followed and the required information is collected and submitted.

Figure 1-2. Use of the Handbook.


Read Chapter 2 - Wetlands Functions and Values
If interested in:
Regulatory requirements and issues
Read Chapter 3
Evaluating a potential wetlands site
Read Chapter 4
Establishing effluent limits or discharge criteria
Read Chapter 5
Designing a wetlands-wastewater system
Read Chapter 6
Implementing or monitoring a wetlands wastewater system
Read Chapter 7
A summary of potential wastewater impacts to wetlands
Read Chapter 8
Assessment techniques or data sources for wetlands
Read Chapter 9
Use appropriate User's Guides to develop needed information for decision making
Develop project if appropriate wetland site is found and permit can be obtained

1.2 RELATIONSHIP OF THE HANDBOOK TO WETLAND ISSUES AND REGULATORY PROCEDURES

Any discharge to a natural wetland must meet the requirements set forth by the Clean Water Act and its wastewater management programs, just as any other water body receiving a discharge. The three major wastewater management programs that will be addressed are the Water Quality Standards, National Pollutant Discharge Elimination System and Construction Grants Programs. The Dredge and Fill Permit Program is most often associated with wetlands. Its impact on the use of wetlands for wastewater management primarily is related to construction activities.

Without wetlands-specific guidance as part of the regulatory framework, evaluation and permitting processes are left open to interpretation, leaving current regulatory practices inconsistent or incomplete. Improving the thoroughness and consistency of assessing wetlands for wastewater management is one of the purposes of the Handbook. The Handbook can help achieve this only by providing guidance on issues that should be incorporated into the regulatory framework. The responsibility of regulatory reform lies with the federal and state agencies which administer the identified Clean Water Act programs.

Many issues identified should be addressed on the regulatory level (e.g., the adequacy of existing use classifications for wetlands). The manner in which the issues are addressed, however, needs to be flexible: each state administering the program may have different needs and objectives. Since the use of wetlands for wastewater management is a developing "technology," a potential user should work closely with the agencies responsible for regulating activities in wetlands. The User's Guide sections should assist the creation of this liaison.

Figure 1-3 indicates how the various chapters of the Handbook relate to decision making and the regulatory process.

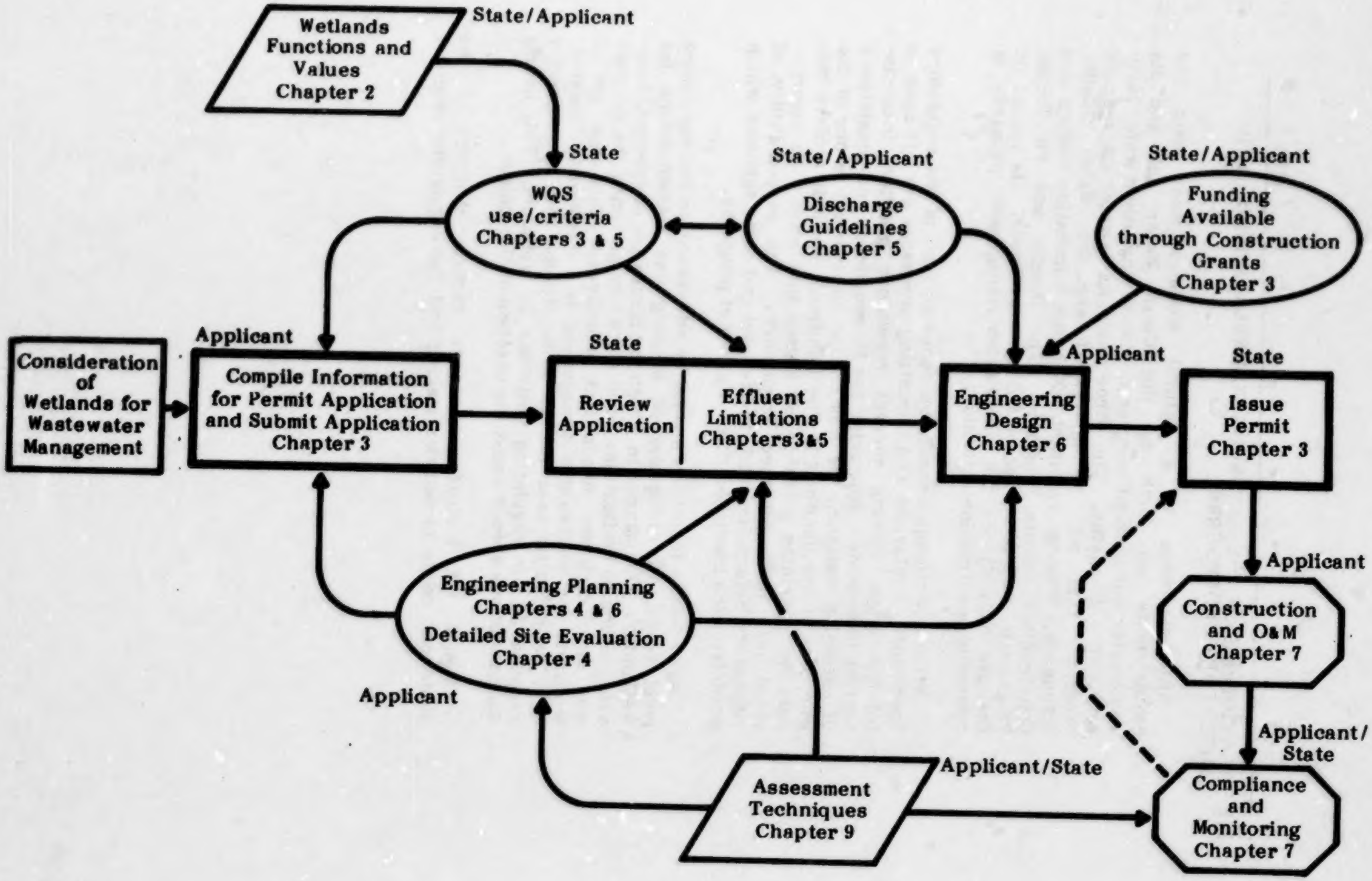

Wetlands Functions and Values Chapter 2
State/Applicant
State
WQS use/criteria Chapters 3 & 5
State/Applicant
Discharge Guidelines Chapter 5
State/Applicant
Funding Available through Construction Grants Chapter 3
Consideration of Wetlands for Wastewater Management
Applicant
Compile Information for Permit Application and Submit Application Chapter 3
State
Review Application
Effluent Limitations Chapters 3&5
Applicant
Engineering Design Chapter 6
State
Issue Permit Chapter 3
Applicant
Construction and O&M Chapter 7
Applicant/State
Compliance and Monitoring Chapter 7
Engineering Planning Chapters 4 & 6
Detailed Site Evaluation Chapter 4
Applicant
Assessment Techniques Chapter 9
Applicant/State

Figure 1-3. Relationship of the Handbook to the Decision Making Process.

1.3 WHY USE WETLANDS IN WASTEWATER MANAGEMENT?

Historically, natural wetlands were used for wastewater management in the Southeast because of convenience or due to the lack of other reasonable alternatives. Few of these discharges were initiated because of the wetland's abilities to renovate wastewater. Some of the wetlands-wastewater systems implemented during the past decade, however, have incorporated design elements to optimize wastewater renovation and preserve wetland integrity.

So, what are the reasons for using wetlands for wastewater management?

1. For a community in the coastal plain and not adjacent to a water course, wetlands may be the only aquatic system available for discharging wastewater. Since groundwater levels and soils may not be conducive to land application, the wetland may be the only reasonable remaining alternative.

2. For communities with a choice between advanced treatment with a surface water discharge and secondary treatment to a wetland, the use of the wetland may be the most affordable alternative.

3. If a community has a partially developed or altered wetland, discharging wastewater might serve to restore flows to the wetland, thereby achieving wastewater management objectives and wetlands restoration/preservation.

4. A wetlands discharge might be the optimal alternative for a small community due to available revenues, wetland proximity or system design.

Other scenarios exist for which the use of wetlands for wastewater management may be reasonable. But not all cases merit such wetlands use. These situations are outlined in the Handbook. The use of wetlands should be avoided when:

1. The wetland under consideration is a pristine wetland and representative of a unique wetland type.

2. Projected impacts to the wetland would cause changes threatening the viability of the wetland (i.e., prevent vegetation reproduction or alter water chemistry characteristics upon which the wetland depends).

3. Conflicts with other uses cannot be mitigated adequately (e.g., preservation of protected species and their habitat).

If these situations are encountered, other sites or management alternatives should be evaluated and selected.

2.0 WETLANDS FUNCTIONS AND VALUES

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2.2 DISTRIBUTION OF WETLANDS IN THE SOUTHEAST 2-2

2.3 OVERVIEW OF FUNCTIONS AND VALUES 2-7
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  2.3.2 Hydrology/Meteorology
    o Flood Control
    o Saltwater Intrusion Control
    o Groundwater Supply
    o Microclimate Regulation
  2.3.3 Water Quality
    o Water Quality Enhancement
  2.3.4 Ecology
    o Habitat for Threatened and Endangered Species
    o Waterfowl Breeding and Habitat
    o Wildlife Habitat
    o Freshwater Fish
    o Aquatic Productivity
    o Nutrient and Material Cycling
  2.3.5 Cultural Resources
    o Harvest of Natural Products
    o Recreation and Aesthetics

2.4 ENDANGERED OR UNIQUE WETLANDS 2-14
  2.4.1 General Regions
  2.4.2 Specific Wetland Areas in the Southeast

2.0 WETLANDS FUNCTIONS AND VALUES

Who should read this chapter? Anyone involved with any aspect of a wetlands-wastewater discharge.

What are some of the issues addressed by this chapter?

- How are wetlands different from other receiving waters?
- What are wetlands functions and values?
- Are unique or endangered wetlands located in the Southeast?

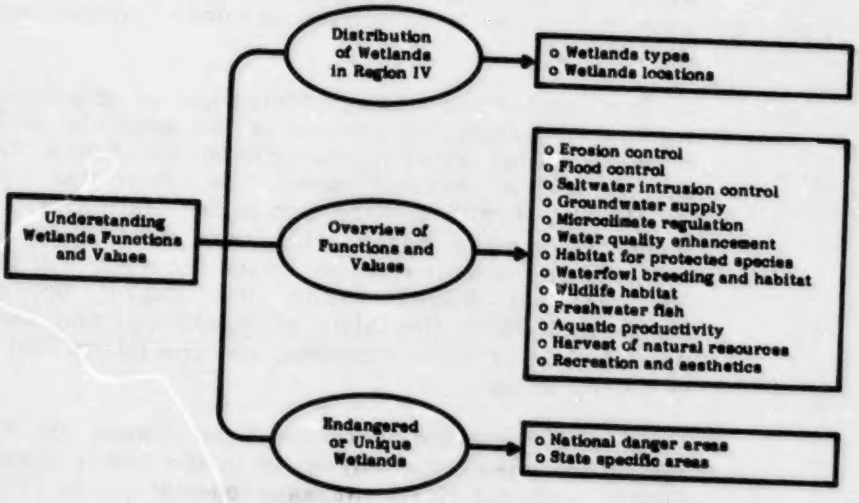

Understanding Wetlands Functions and Values
Distribution of Wetlands in Region IV
o Wetlands types
o Wetlands locations
Overview of Functions and Values
o Erosion control
o Flood control
o Saltwater intrusion control
o Groundwater supply
o Microclimate regulation
o Water quality enhancement
o Habitat for protected species
o Waterfowl breeding and habitat
o Wildlife habitat
o Freshwater fish
o Aquatic productivity
o Harvest of natural resources
o Recreation and aesthetics
Endangered or Unique Wetlands
o National danger areas
o State specific areas

Figure 2-1. Overview of Wetlands Functions and Values

2.1 PURPOSE AND CONSIDERATIONS

Before any wetlands-wastewater management system is considered seriously, the major functions and values of wetlands should be understood. While not all wetlands display all the functions and values discussed below, every wetland is characterized by some combination of the functions and values presented. Since wetlands protection should be a prime objective of any wetlands-wastewater management system, and the basis for wetlands related water quality standards, a broad understanding of how wetlands function and what values they provide is essential. Figure 2-1 provides a brief overview of the important elements of this chapter.

2.2 DISTRIBUTION OF WETLANDS IN THE SOUTHEAST

In the mid-1970's, approximately 99 million acres of wetlands existed in the continental United States (excluding Alaska and Hawaii). This represents about 5 percent of the nation's land surface. Inland freshwater wetlands accounted for almost 94 million acres of the total. These acreages represent the wetlands remaining after more than 20 years of losses, during which time about 450,000 acres per year were destroyed in the entire United States (U.S. FWS 1984). As a result, it is important that wetlands functions and values are clearly understood, particularly if they are to be subject to human-induced development or management.

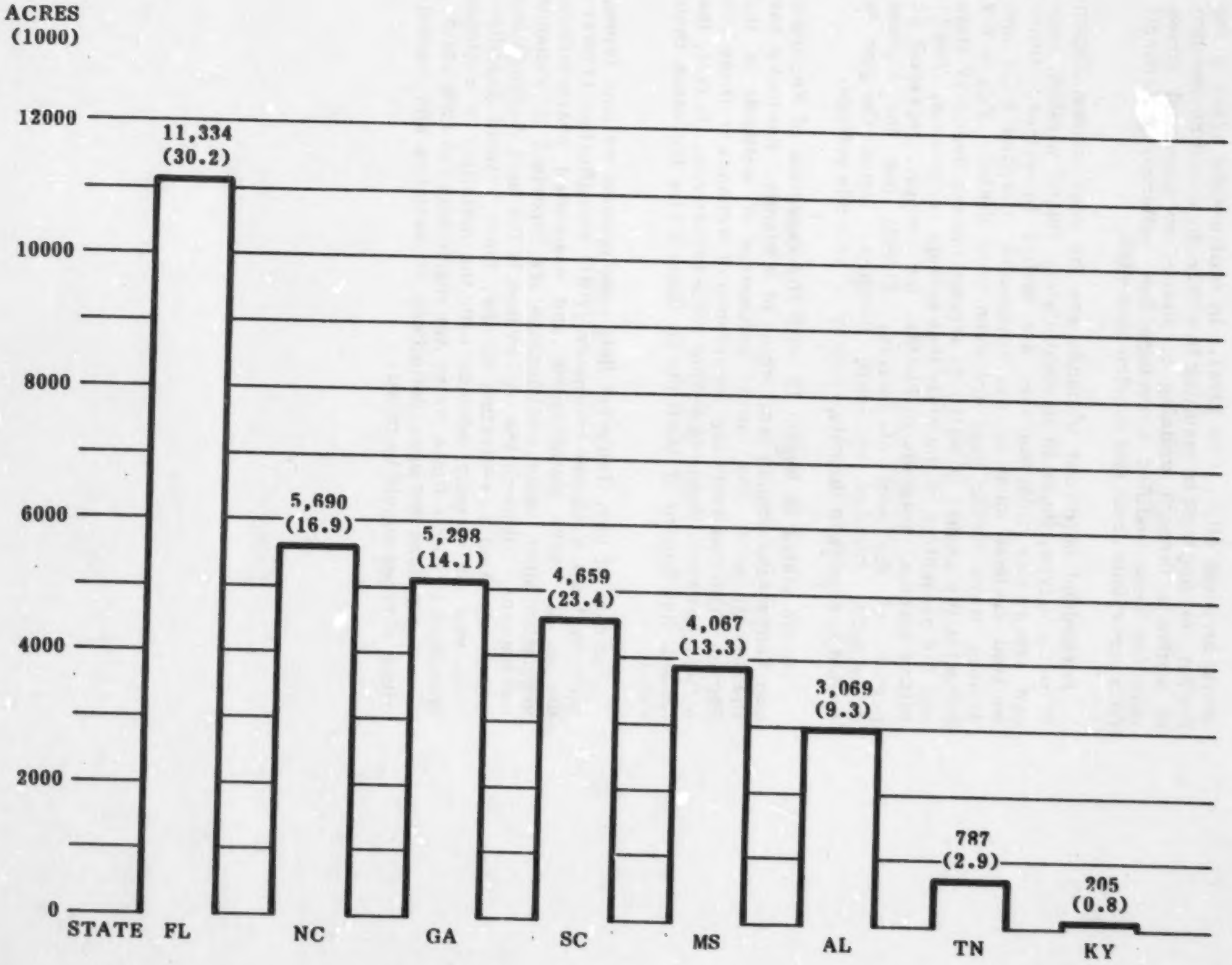
The Southeastern United States has an abundance of natural wetlands. In fact, 35 percent of the wetlands remaining in the lower 48 states occur in the eight states of EPA Region IV. Of the 9 million wetland acres lost from the mid-1950's to mid-1970's, 8 million were lost in the Southeast. This acreage incorporates major losses in Louisiana outside EPA Region IV but a significant amount of these losses occurred within the Region. The greatest losses within the Region occurred in the Mississippi River floodplain of Mississippi and Tennessee, the coastal plain of North Carolina, and the inland and coastal areas of south Florida.

In the Southeast, most wetland losses are the result of agricultural drainage, especially in the Lower Mississippi Delta, Florida and the North Carolina coastal plain. Clearcutting of bottomland hardwoods for timber is followed by draining soils for crop production, primarily soybeans. Also, many inland wetlands are being converted to pine plantations throughout the Region. In Florida and North Carolina, phosphate mining also is destroying extensive wetland areas. Specific to North Carolina, pocosin wetlands are being drained for agricultural use and mined for peat (U.S. FWS 1984). In most coastal areas in the Region, development is resulting in either the direct destruction of wetlands through draining or filling, or increased stress resulting from modified hydrologic/flow patterns, and runoff from impervious areas and construction sites.

Bottomland hardwood wetlands are the most common Region IV wetland type, found in all eight states. Inland marshes, bogs and freshwater tidal marshes are limited in extent. Other wetland systems such as wet savannahs, Carolina Bays and Atlantic White Cedar Bogs are even more limited. Figure 2-2 indicates the amount of wetlands acreage in each Region IV state and the percentage of the state that acreage represents. The 11 million acres of wetlands in Florida, for example, represent 30 percent of the area of Florida. Florida has the highest percentage, followed by South Carolina. North Carolina is second to Florida in the actual amount of wetlands acreage.

All the states in Region IV with the exception of Kentucky and Tennessee, contain large areas of wetlands. Kentucky has the fewest acres and lowest percentage of wetlands in the Region. The relatively low occurrence of wetlands in these two states, however, does not reduce their importance. In fact, the limited distribution of wetlands in these states increases their value.

For ease of use, Table 2-1 lists some common wetland types, their National Wetlands Inventory (NWI) classification (Cowardin et al. 1979) counterparts and associated characteristic vegetation since these relationships are important to wetlands management. Although the NWI system is the most thorough and widely accepted classification scheme, these wetland classifications may not directly coincide with the definition of wetlands contained in EPA's Clean Water Act regulations (40 CFR 122.2). The distinctions between definitions of wetlands and classification of types should be noted.



Source: Adapted from
Hefner and Brown 1984

Figure 2 Wetland Acreages for the eight states in the Southe
(Percentage of state as wetlands)

Table 2.1. Relationship Between Common Wetland Types and the National Wetlands Inventory (Cowardin et al. 1979). Classification System.

Common Wetland Types*	National Wetlands Inventory (Fish and Wildlife Service) System Type	Class	Subclass	Characteristic Flora Common name (Botanical name)
Hydrologically Isolated System				
Wooded swamp	Palustrine	Forested wetland	Broad-leaved deciduous	Water tupelo (*Nyssa aquatica*); swamp black gum (*N. biflora*); Ogeechee plum (*N. ogeche*); water elm (*Planera aquatica*); Carolina ash (*Fraxinus caroliniana*); bald cypress (*Taxodium distichum*); fetter bush (*Lyonia lucida*); leatherbush, titi (*Cyrilla racemiflora*); common alder (*Alnus serrulata*); wax myrtle (*Myrica cerifera*); black willow (*Salix nigra*); buttonbush (*Cephalanthus occidentalis*); Virginia willow (*Itea virginica*); overcup oak (*Quercus lyrata*); red maple (*Acer rubrum* var. drummondii)
Cypress dome	Palustrine	Forested wetland	Needle-leaved deciduous	Bald cypress (*Taxodium distichum*); pond cypress (*T. ascendens*)
Bog, pocosin, Carolina bay, evergreen shrub-bog, bay head	Palustrine	Scrub-shrub wetland	Broad-leaved deciduous	Leatherbush, titi (*Cyrilla racemiflora*); fetterbush (*Lyonia lucida*); inkberry, holly (*Ilex glabra*); Zenobia (*Zenobia pulverulenta*); pond pine (*Pinus serotina*); red maple (*Acer rubrum*); bay magnolia, white bay (*Magnolia virginiana*); loblolly bay (*Gordonia lasianthus*); southern white cedar (*Chamaecyparis thyoides*); swamp bay (*Persea borbonia*); wax myrtle (*Myrica cerifera*); pepperbush (*Clethra alnifolia*)
Shrub swamp	Paulstrine	Scrub-shrub wetland	Broad-leaved deciduous	Common alder (*Alnus serrulata*); swamp privet (*Forestiera acuminata*); black willow (*Salix nigra*); buttonbush (*Cephalanthus occidentalis*); Carolina willow (*S. caroliniana*); Virginia willow (*Itea virginica*)
Pine flatwoods, pine swamp	Palustrine	Forested wetland	Needle-leaved evergreen	Pond pine (*Pinus serotina*); loblolly pine (*P. taeda*); slash pine (*P. elliottii*); longleaf pine (*P. palustris*); wax myrtle (*Myrica cerifera*); titi, leatherbush, (*Cyrilla racemiflora*)
Shallow freshwater marsh, deep freshwater marsh, inland marsh, bogue, prairie, savannah	Palustrine	Emergent wetland	Persistent; non-persistent	Cattail (*Typha* spp.); bulrush (*Scirpus* spp.); maidencane (*Panicum hemitomon*); lizards tail (*Saururus cernuus*); alligatorweed (*Alternanthera philoxeroides*); sedge (*Carex* spp., *Cyperus* spp., *Rhynchospora* spp.); rush (*Juncus* spp., *Eleocharis* spp.); reed (*Arundo donax*, *Phragmites communis*); aster (*Aster*); beggartick, stick-tight (*Bidens* spp.); water hemlock (*Cicuta maculata*); sawgrass (*Cladium jamaicense*); barnyard grass (*Echinochloa crusagalli*); spikerush (*Eleocharis* spp.); joe-pye weed, late boneset (*Eupatorium* spp.), mallow (*Hibiscus* spp.); iris (*Iris virginica*, *Iris* spp.); purslane (*Ludwigia* spp.); maidencane, switchgrass (*Panicum* spp.); joint grass (*Paspalum distichum*); pelandra (*Peltandra virginica*); smartweed (*Polygonum* spp.); pickerelweed (*Pontederia cordata*); arrowhead (*Sagittaria* spp.)

*Wooded swamps, marshes, wet prairies and bogs can be either hydrologically isolated from or connected to other surface waters.

Table 2.1. Continued.

Common Wetland Types	National Wetlands Inventory (Fish and Wildlife Service)			Characteristic Flora
	System Type	Class	Subclass	Common name (Botanical name)
Savannah, wet prairie	Palustrine	Emergent wetland	Persistent; non-persistent dependent on dominants	Grass pink (*Calopogon* spp.); coastal milkweed (*Asclepias* spp.); pitcher plant (*Sarracenia* spp.); St. Johns' wort (*Hypericum* spp.) toothache grass (*Ctenium* spp.); club-moss (*Lycopodium prostratum*); bog-button (*Lachnocaula anceps*); sea pinks (*Sabatia* spp.); yellow-eyed grass (*Xyris* spp.); meadow-beauty (*Rhexia* spp.); marsh fleabane (*Pluchea* spp.); muhly (*Muhlenbergia* spp.); *Aristida* spp.; lobelia (*Lobelia* spp.); nutrush (*Scleria* spp.); sun dew (*Drosera* spp.); *Pagonia* spp.; milkwort (*Polygala lutea*); pipewort (*Eriocaulon* spp.); bog-orchid (*Habenaria* spp.); sedge (*Dichromena* spp.)
Meadow, wet meadow fresh meadow	Palustrine	Emergent wetland	Persistent; Non-persistent (dependent on dominant)	Sedge (*Carex* spp.); flat sedge (*Cyperus* spp.); rush (*Juncus* spp.); beaked sedge (*Rhynchospora* spp.) tickweed, beggartick, stick-tight (*Bidens* spp.); aster (*Aster* spp.); goldenrod (*Solidago* spp.); joint-grass, para grass (*Panicum* spp.); broom straw (*Andropogon* spp.)
Hydrologically Connected				
Marsh, bayou, brake, ox-bow, swamp creek, flat, prairie-marsh, slough	Palustrine Lacustrine Riverine	Aquatic bed	Various dependent on dominants	Watershield (*Brasenia schreberi*); fanwort, cabomba (*Cabomba caroliniana*); hornwort (*Ceratophylum* spp.); water hyacinth (*Eichornia crassipes*); *Elodea* spp.; duckweed (*Lemna* spp.); pennywort (*Hydrocotyle* spp.); southern niad (*Najas* spp.); lotus (*Nelumbo lutea*); spatterdock (*Nuphar advena*); white water lily (*Nymphaea oderata*); pondweed (*Potomogeton* spp.); duckmeat (*Spirodela polyrrhiza*); bladderwort (*Utricularia* spp.); salvinia (*Salvinia auriculata*); mosquito fern (*Azolla caroliniana*)
Mixed bottomland hardwood, hardwood strand	Palustrine	Forested	Broad-leaved deciduous	Laurel oak (*Quercus laurifolia*); willow oak (*Q. phellos*); swamp chestnut (*Q. michauxii*); cherry bark oak, swamp Spanish oak (*Q. pagoda*); loblolly pine (*P. taeda*); American white elm (*Ulmus americana*); sweetgum (*Liquidambar styraciflua*); river birch (*Betula nigra*); ironwood, blue beech (*Carpinus caroliniana*); palmetto, dwarf palmetto (*Sabel minor*); cabbage palm (*Sabel palmetto*)
Marsh	Riverine Lacustrine	Emergent wetland	Persistent; non-persistent (dependent on dominants)	Lizards tail (*Saururus cernuus*); alligator weed (*Alternanthera philoxeroides*); sedge (*Eleocharis* spp.); iris (*Iris virginica*); pelandera (*Peltandra virginica*); smartweed (*Polygonum* spp.); pickeral weed (*Pontederia cordata*); wild rice (*Zizania* spp.); bulrush (*Scirpus* spp.); rush (*Juncus* spp.)
Cypress Strand	Palustrine	Forested wetland	Needle-leaved deciduous	Bald cypress (*Taxodium distichum*); pond cypress (*T. ascendens*)

2.3 OVERVIEW OF WETLAND FUNCTIONS AND VALUES

Wetlands have many important roles in the maintenance of ecosystems and watersheds. The terms function and value are often used together to describe or characterize a wetland. Wetland functions are the inherent processes or capabilities of wetlands. Most of the values of wetlands relate directly to these functions: for example, the water quality enhancement functions of wetlands are one of their great values. Some wetland values, such as visual-cultural values, are somewhat independent of wetland function. Typically the functions and values of wetlands are interrelated.

The following 16 functions and values of wetlands summarized in Table 2-2 are widely accepted.

Table 2-2. Primary Wetland Functions and Values

Geomorphology

- Erosion control

Hydrology/Meteorology

- Flood control
- Saltwater intrusion control
- Groundwater supply
- Microclimate regulation

Water Quality

- Water quality enhancement

Ecology

- Habitat for threatened and endangered species
- Waterfowl breeding and habitat
- Wildlife habitat
- Freshwater fish (and some marine species)
- Aquatic productivity
- Nutrient/material cycling

Cultural Resources

- Harvest of natural products
- Recreation and aesthetics

2.3.1 Geomorphology

Erosion Control. Located between watercourses and uplands, wetlands help protect uplands from erosion. Wetland vegetation can reduce shoreline erosion in several ways, including: (1) increasing stability of the sediment through binding with its roots, (2) dampening waves through friction and (3) reducing current velocity through friction. These processes reduce turbidity and thereby improve water quality. Rich, alluvial soils, which build up in wetlands, also contribute to productivity.

Wetland vegetation has been successfully planted to reduce erosion along U.S. waters. While most wetland plants need calm or sheltered water for establishment, they will effectively control erosion once established. Willows, alders, ashes, cottonwoods, poplars, maples and elms are particularly good stabilizers. Successful emergent plants in freshwater areas include reed canary grass, reed, cattail, and bulrushes. Sediment deposition in freshwater wetlands also acts to decrease siltation in downstream systems such as estuaries.

2.3.2 Hydrology/Meteorology

Flood Control. Wetlands temporarily store flood waters and thus reduce downstream losses of life and property. Since destruction from floods in the U.S. runs from $3 to $4 billion each year, the damage-diminishing function of wetlands is vitally important.

Rather than having all flood waters flowing rapidly downstream and destroying private property and crops, wetlands slow the flow of water, store it for some time and slowly release stored waters downstream. In this way, flood peaks of tributary streams are desynchronized and all flood waters do not reach the mainstem river at the same time. This function becomes more important in urban areas, where development has increased the rate and volume of surface water runoff and the potential for flood damage (U.S. FWS 1984).

Saltwater Intrusion Control. The flow of freshwater through wetlands creates groundwater pressure that prevents saltwater from invading public water supplies. This is important only where freshwater wetlands interface with an estuarine environment (U.S. FWS 1984).

Groundwater Supply. There is considerable debate over the role of wetlands in groundwater recharge. Recharge potential of wetlands varies according to numerous factors, including wetland type, geographic location, season, soil type, water table location and precipitation. Depressional wetlands like cypress domes in Florida and prairie potholes in the Dakotas may contribute to groundwater recharge. Floodplain wetlands also may do this through overbank water storage (U.S. FWS 1984). As a result, the protection of this function could be a factor in addressing current and future water supply problems.

Microclimate regulation. Although less is known about the role of wetlands in regulating climatic conditions than about many other wetlands functions, available data indicate this may be a significant wetland function. In some cases wetlands appear to modify air temperatures, affect localized precipitation and maintain global atmospheric stability. Most available information concerning the modification of air temperatures and regional precipitation is pertinent for Florida wetlands, which comprise such a large percentage (30%) of the state. It has been suggested that thunderstorm activity could decrease in Florida as a result of draining wetlands, thereby modifying water budgets (EPA 1983).

2.3.3 Water Quality

Water Quality Enhancement. Wetlands act as natural water purification mechanisms. They remove silt, and filter out and absorb nutrients and many pollutants such as waterborne toxic chemicals.

Water quality enhancement is dependent on wetlands soils, vegetation, flow through time, water depth and related processes. Many communities throughout the United States, including more than 400 communities in the Southeast, have benefitted from the capabilities of wetlands to enhance water quality by incorporating wetlands into their wastewater management systems (EPA 1983).

2.3.4 Ecology

Habitat for Threatened and Endangered Species. More than 20 percent of all the plant and animal species on the Federal Endangered or Threatened Species list are dependent on wetlands for food and/or habitat. Fifteen wetlands dependent species on the federal list are found only in the Southeast. Additionally, each state has a list of protected species and many of these in each state are wetlands dependent: Alabama - 25 species; Florida - 31 species; Georgia - 6 species; Kentucky - 14 species; Mississippi - 14 species; North Carolina - 8 species, South Carolina - 13 species; Tennessee - 13 species (EPA 1983).

Waterfowl Breeding and Habitat. Over 12 million ducks nest and breed annually in northern U.S. wetlands. This area, when combined with similar habitats in the Canadian prairies, accounts for 60 to 70 percent of the continent's breeding duck population. Waterfowl banded in North Dakota have been recovered in 46 states, 10 Canadian provinces and territories, and 23 other countries. Some 2.5 million of the 3 million mallards in the Mississippi Flyway and nearly 100 percent of our 4 million wood ducks spend the winter in flooded bottomland forests and marshlands throughout the South.

Bottomland forested wetlands of the South are primary wintering grounds for North American waterfowl areas, as well as important breeding areas for wood ducks, herons, egrets and white ibises. Even wild turkeys nest in bottomland hardwood forests. Other common bird inhabitants include barred owls, downy and redbellied woodpeckers, cardinals, pine warblers, wood peewees, yellowthroats and wood thrushes (U.S. FWS 1984).

Wildlife Habitat. Wetlands provide food and shelter for a great variety of furbearing animals and other kinds of wildlife. Louisiana marshes alone yield an annual fur harvest worth $10 to $15 million (U.S. FWS 1984).

Muskrats, beavers and nutria are the most common fur bearers dependent on wetlands. Muskrats are the most wide ranging of the three, inhabiting both coastal and inland marshes throughout the country. In contrast, beavers tend to be restricted to inland wetlands, with nutria limited to coastal wetlands of the South. Other wetland-utilizing furbearers include otter, mink, raccoon, skunk and weasels. Other mammals also frequent wetlands, such as marsh and swamp rabbits, numerous mice, bog lemmings and shrews. Larger mammals may also be observed. Black bears find refuge and food in shrub wetlands in South Carolina, for example (U.S. FWS 1984).

Turtles, snakes, reptiles and amphibians are all common residents of wetlands in the Southeast. Alligators range from Florida to North Carolina to the north, and Texas to the west.

Freshwater Fish. Many of the 4.5 million acres of open water areas found in inland wetlands are ideal habitat for such sought after species as bass, catfish, pike, bluegill, sunfish, and crappie.

Most freshwater fishes can be considered wetland-dependent because: (1) many species feed in wetlands or upon wetland-produced food; (2) many fishes use wetlands as nursery grounds and (3) almost all important recreational fishes spawn in the aquatic portions of wetlands. Bottomland hardwood forests of the South serve as nursery and feeding grounds for young warmouth and largemouth bass, while adult bass feed and spawn in these wetlands. River swamps in Georgia produce 1,300 pounds of fish per acre. The bottomlands of the Altamaha River in Georgia are spawning grounds for the hickory shad and blueback herring. Southern bottomland forested wetlands are also the home of the edible red swamp crayfish, which burrow down to the water table when flooding waters recede (U.S. FWS 1984).

Aquatic Productivity. Wetlands are among the most productive ecosystems in the world. Wetland plants are particularly efficient converters of solar energy. Through photosynthesis, plants convert sunlight into plant material or biomass and produce oxygen as a by-product. This biomass serves as food for a multitude of animals, both aquatic and terrestrial. For example, many waterfowl depend heavily on seeds of marsh plants, while muskrat eat cattail tubers and young shoots.

Generally, direct grazing of wetland plants is limited, so the vegetation's major food value is produced when it dies and fragments, forming detritus. This detritus forms the base of an aquatic food web which supports higher consumers. Wetlands can be regarded as the farmlands of the aquatic environment, producing great volumes of food annually. The majority of non-marine aquatic animals depend, either directly or indirectly, on this food source (U.S. FWS 1984).

Nutrient and Material Cycling. Implicit in the discussion of several other wetland functions and values is the importance of wetlands to downstream ecosystems. Wetlands that are hydrologically connected to surface waters often serve as an important source of nutrients and organic matter. Wetlands serve to break down organic matter, such as dead vegetation, and to cycle nutrients so these materials are useable in downstream ecosystems. This function is essential to many freshwater and marine organisms in downstream waters and estuaries (Day 1981).

2.3.5 Cultural Resources

Harvest of Natural Products. A variety of natural products are produced in freshwater wetlands, including timber, fish, water fowl, pelts and peat. Wetland grasses are hayed in many places for winter livestock feed. During other seasons, livestock graze directly in wetlands across the country. These and other products are harvested by man for his use and provide a livelihood for many people. The standing value alone of southern wetland forests is $8 billion. Conversion of bottomland forests to agricultural fields (e.g., soybeans) in the Mississippi Delta has reduced these wetlands by 75 percent.

Wetlands also support fish and wildlife for man's use. Commercial fishermen and trappers make a living from these resources. Many commercial species (catfish, carp and buffalo fish) depend on freshwater wetlands for habitat, nutrients or organic matter. Furs from beaver, muskrat, mink, nutria and otter yielded roughly $35.5 million in 1976. Louisiana is the largest fur-producing state, and nearly all furs come from wetland animals.

Many wetlands produce peat, a resource used mainly for horticulture and agriculture in the United States. Peat mining, however, destroys wetlands and their many associated values (U.S. FWS 1984).

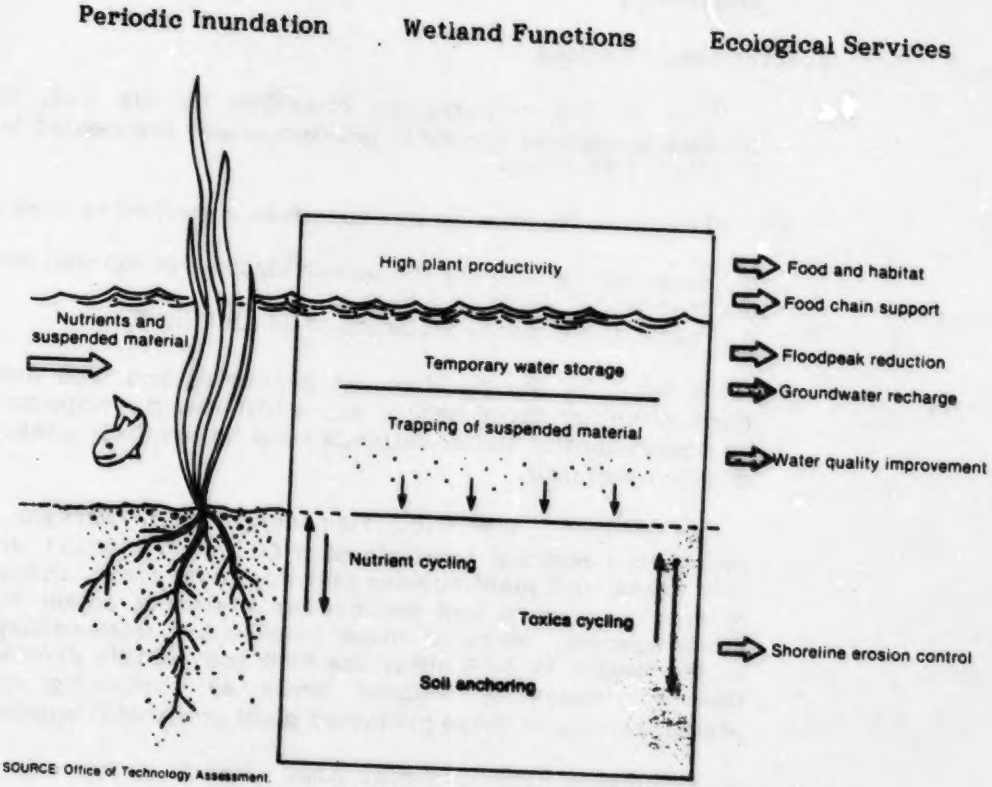
Recreation and Aesthetics. Many recreational activities take place in and around wetlands. Hunting and fishing are popular sports. Waterfowl hunting is a major activity in wetlands, and big game hunting is also important locally.

Other recreation in wetlands is largely non-consumptive: hiking, nature observation and photography, swimming, boating and ice-skating. Many people simply enjoy the beauty and sounds of nature and spend their leisure time walking or boating in or near wetlands observing plant and animal life. The aesthetic value of wetlands is extremely difficult to evaluate or place a dollar value upon. Nonetheless, it is very important. In 1980 alone, 28.8 million people (17 percent of the U.S. population) took special trips to observe, photograph or feed wildlife.

Figure 2-3 graphically depicts many of the major wetlands functions and values. These functions and values are important to the use of wetlands for wastewater management for several reasons. First and foremost, they provide the basis for water quality standards and the nondegradation of existing uses. Existing uses, as represented by the list of beneficial wetland functions and values, must be clearly identified and protected by a wastewater management plan incorporating wetlands.

While few wetlands will exhibit all 16 attributes listed, the existing values must be identified for each prospective site. Not only do these functions and values serve as a basis for regulatory considerations, they also impact site screening, engineering design, operation and monitoring of a prospective wetlands discharge. Wastewater management objectives must be considered in light of environmental protection. The Handbook emphasizes the importance of wetlands functions and values in each of the three major subject areas addressed: institutional, scientific and engineering considerations.

Figure 2-3. Relationship Between Wetland Functions and Values.



Periodic Inundation
Wetland Functions
Ecological Services
High plant productivity
Nutrients and suspended material
Temporary water storage
Trapping of suspended material
Nutrient cycling
Toxics cycling
Soil anchoring
Food and habitat
Food chain support
Floodpeak reduction
Groundwater recharge
Water quality improvement
Shoreline erosion control

SOURCE: Office of Technology Assessment.

2.4 ENDANGERED OR UNIQUE WETLANDS

In the past, endangered or unique wetlands were not acknowledged because little value was placed on wetlands. As wetlands have been lost to a variety of competing uses through the years, their distribution and occurrence has been examined more thoroughly. Now, in conjunction with the acknowledged values of wetlands, the concept of endangered or unique wetlands is not only valid, but also essential to their use and protection.

2.4.1 General Regions

Four of the nine regions classified by the U.S. Fish and Wildlife Service as "national problem areas" are located in Region IV (U.S. FWS 1984).

The three freshwater wetland areas classified as such are:

- Forested Wetlands of the Lower Mississippi Alluvial Plain
- Pocosins of North Carolina
- Palustrine (inland) wetlands of South Florida.

As a result of the development pressures and land use alterations affecting these areas, any additional development around or management of these wetlands must be carefully evaluated and closely monitored.

In addition, the U.S. Fish and Wildlife Service recently prepared a regional strategic plan (U.S. FWS 1984b) which targets animal and plant species that are endangered, threatened or of special concern and establishes a plan of action to protect those species. Many of these species are wetland-dependent. In the Region IV EPA area, the Fish and Wildlife Service identified the following wetland areas as containing significant concentrations of these protected plant and animal species:

- Tennessee River Drainage Area - has 24 listed endangered or threatened species, all endemic to the area
- Coastal wetlands of the Atlantic and Gulf states
- South Florida - has 20 listed endangered or threatened species.

This survey led to the identification of endangered or unique wetland types within each state. Table 2-3 shows unique and endangered wetland types for each state, along with some clarifying comments. Endangered wetlands are defined here as those areas being impacted by development pressures or other stresses. Unique wetlands refers to those wetland types which are limited in extent and/or act as habitats for endangered, rare or threatened species. It should be noted that several of these

Table 2-3. Endangered or Unique Wetland Types in EPA Region IV States

State	Endangered	Unique	Comments	Source
Alabama	o Bottomland hardwoods Cypress-tupelo swamps Coastal marshes Pitcher Plant bogs		o Extent of these types has been severely reduced in last 30 years due to human activities, including agriculture and forestry. BLH and coastal marshes are sensitive to hydroperiod change.	U.S. FWS, AL
		o Pitcher plant bogs	o Most limited in distribution and also sensitive to hydroperiod change.	U.S. FWS, AL
Florida (excluding the Everglades & Big Cypress Swamp areas)	o Riverine systems	o Wet prairies	o Wet prairies are the habitat for endangered plant species Harper's Beauty, *Harperocallis flava*.	U.S. FWS, FL
		o Cypress swamps that are woodstork rookeries		FL Natural Areas Inventory
Georgia	o Freshwater tidal marshes o Blackwater swamps		o Those associated with major rivers and tidal rivers should be protected from being drained or converted to other uses.	GA DNR Marsh & Beach Div. Game & Fish Div.
		o Lime sinks o Carolina Bays		SC Natural Heritage Trust
Kentucky	o Bottomland Hardwoods	o Cypress sloughs o Oxbows		KY Nature Conservancy U.S. FWS, TN Univ. of Louisville
	Kentucky has a small percentage of wetlands. This fact makes these wetlands valuable in as much as they are of limited distribution and continue to be stressed by development pressures, including forestry, strip mining of coal and agriculture.			
Mississippi	o Bottomland Hardwoods o Coastal marshes		o Extent severely reduced in last 30 years due to human activities, including agriculture and forestry. BLH and coastal marshes are sensitive to hydroperiod change.	U.S. FWS, AL & MS
		o Pitcher plant bogs	o Limited in distribution and sensitive to hydroperiod change.	
		o Savannahs	o Limited in distribution.	MS Natural Heritage Program

Table 2-3. Continued.

State	Endangered	Unique	Comments	Source
North Carolina	o Unaltered Pocosins o Unaltered Carolina Bays o Non-alluvial swamp forests		o Endangered due to development pressures. o All wetlands within the state are stressed by development in varying degrees.	U.S. FWS, NC
		o Mountain bogs o White cedar forests o Freshwater wetlands on barrier islands o Freshwater tidal wetlands o Seepage bogs o Nonriverine swamp forests o Vernal pools o Clay-based Carolina Bays	o These are of limited occurrence and may contain many disjunct, threatened or endangered natural communities and species.	NC Natural Heritage Program
	o Peat-filled Carolina Bays o Pocosins o Pine savannahs o Pond pinewood lands and forests o Brownwater alluvial wetlands o Blackwater alluvial wetlands		o These have been extensively subjected to drainage, farming, road building, etc.	NC Natural Heritage Program
South Carolina		o Grass-sedge dominated Carolina Bays	o These are habitats for significant rare plant species.	SC Natural Heritage Trust
		o Lime sinks		
		o Continuous seepage bogs	o Habitat for the endangered species--Bunched Arrowhead.	
		o Carolina Bays	o Limited in distribution, habitat for pond pine-scrub community.	U.S. FWS, SC
		o Piedmont streams/ rocky shoals	o Habitat for the spider lily (Hymenocallis coronaria).	
		o Pocosins	o Limited in distribution.	
			o Cypress-tupelo communities are extremely sensitive to hydroperiod change.	

Table 2-3. Continued.

State	Endangered	Unique	Comments	Source
Tennessee		o Perched wetlands	o Limited distribution of these groundwater seep wetlands, located along the Highland Rim. Have highly sensitive biotic communities and interact with groundwater due to karst topography.	U.S. FWS, TN
	o Bottomland Hardwoods o Bogs & bogponds o BLM o Cypress swamps o Maidencane marshes o Buttonbush marshes o Sphagnum ponds		o All wetlands in Tennessee are considered of high value. Lower priority is given to the Coastal Plain wetlands in western Tennessee.	TN Natural Heritage Program

wetland types could fall into both categories. They are not listed as such in Table 2-3. Wetland types vary in distribution in each state, so what may be unique in Tennessee may not be in Mississippi. The use of unique wetland types listed in Table 2-3 as wastewater management systems is discouraged. Those listed as endangered are generally not good candidates for use as wastewater management systems; however, specific sites might be considered for use after thorough environmental assessments. Some systems endangered by development might actually be enhanced or protected by a wastewater discharge.

2.4.2 Specific Wetland Areas in the Southeast

Identification and evaluation of the unique or endangered levels of specific wetlands is an ongoing process. Information on specific wetlands within Region IV was gathered from U.S. Fish and Wildlife field offices, State Natural Heritage Programs and the Nature Conservancy. Maps showing unique or endangered wetlands may be obtained from the State Natural Heritage Program offices. If a proposed wetland-wastewater management system is located near such an area, a potential discharger should work closely with the appropriate regulatory agencies. These agencies, identified in Section 9.6, will help determine if the wetland is of special concern.

There are 83 National Wildlife Refuges in the U.S. FWS Southeast Region (which includes Louisiana and Arkansas). Many of these lands are wetlands and are managed for the benefit of migratory birds. Wetland areas in these refuges should be considered protected and not available for wastewater use unless a wastewater discharge can be shown to maintain or enhance habitat.

The Nature Conservancy identifies "priority aquatic sites for biological diversity conservation." The areas included in this list must meet one or more of the following criteria:

1. Best intact remnants of damaged or declining systems
2. Best opportunities for protection of representative viable examples of major regional systems
3. Sites of endangered species
4. Sites of endangered natural communities.

The list of these sites is in draft form (1984), yet is extensive and includes many wetland areas in the Southeastern U.S. The state or National Nature Conservancy office should be contacted to identify these sites (see Table 9-46). Each state (except Georgia) has a Natural Heritage Program which identifies rare, endangered or significant plant and animal species, natural communities and other natural features.

3.0 INSTITUTIONAL ISSUES AND PROCEDURES

3.1 WASTEWATER MANAGEMENT PROGRAMS AND APPLICATIONS TO WETLANDS 3–2

- **3.1.1 Purpose and Background**
- **3.1.2 Wastewater Management Programs**
- **3.1.3 Other Federal Programs and Policies**
- **3.1.4 Fundamental Institutional Considerations**
- **3.1.5 Existing State Policies/Programs**
  - o Alabama
  - o Florida
  - o Georgia
  - o Kentucky
  - o Mississippi
  - o North Carolina
  - o South Carolina
  - o Tennessee
- **3.1.6 Local Regulatory Responsibilities**

3.2 WATER QUALITY STANDARDS PROGRAM 3–16

- **3.2.1 WQS Purpose and Background**
  - o Use Attainability
  - o Natural Background Conditions
  - o Site-specific or Generic Criteria
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- **3.2.2 WQS Program Requirements and Current Practices**
- **3.2.3 WQS Wetland Discharge Considerations**
- **3.2.4 Alternatives for WQS Wetland Discharge Considerations**

3.3 NPDES PERMIT PROGRAM 3–37

- **3.3.1 NPDES Purpose and Background**
  - o Permit Application
  - o Effluent Limitations
  - o Permit Requirements
  - o Compliance/Monitoring
- **3.3.2 NPDES Program Requirements and Current Practices**
- **3.3.3 NPDES Wetland Discharge Considerations**
- **3.3.4 Alternatives for NPDES Wetland Discharge Considerations**

3.4 CONSTRUCTION GRANTS PROGRAM 3–60

- **3.4.1 Construction Grants Purpose and Background**
  - o The Facilities Planning Process
  - o The Design and Construction Processes
- **3.4.2 Construction Grants Program Requirements and Current Practices**
- **3.4.3 Construction Grants Wetland Discharge Considerations**
- **3.4.4 Alternatives for Construction Grants Wetland Discharge Considerations**
  - o Incorporation of Wetland Specific Components into the Construction Grants Program

3.5 USER'S GUIDE 3–72

3.0 INSTITUTIONAL ISSUES AND PROCEDURES

Who should read this chapter? Regulatory agency personnel.

What are some of the issues addressed by this chapter?

- How do water quality standards apply to wetlands and wetland discharges?
- How are wetland discharges permitted under the NPDES permit program?
- Are wetlands discharge projects fundable under EPA's Construction Grants program?

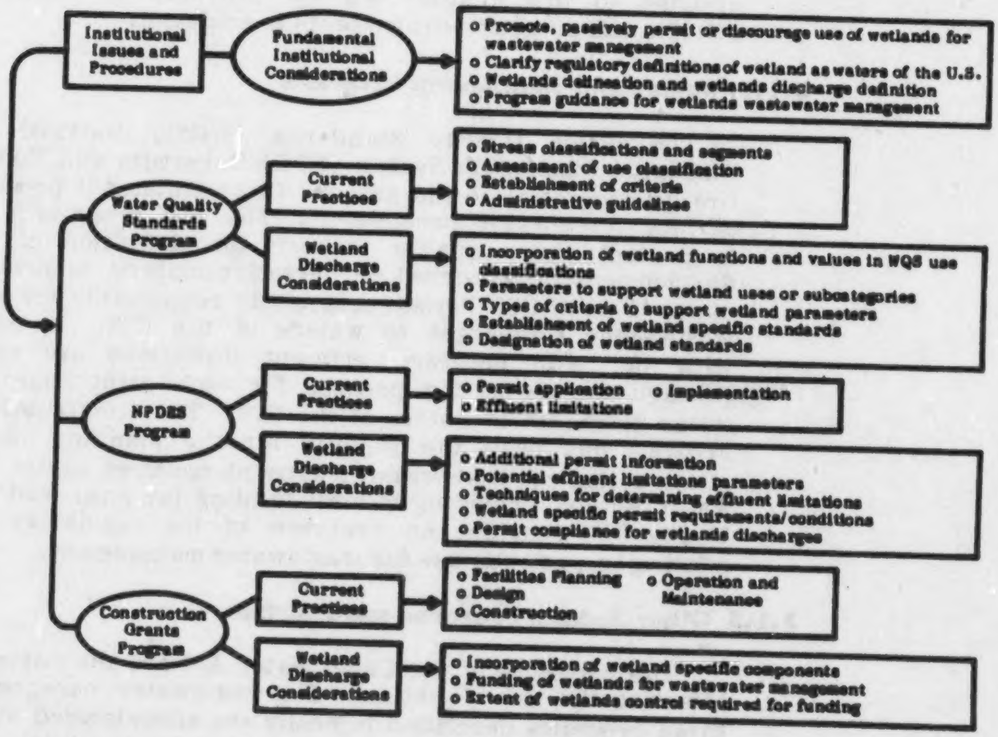

Institutional Issues and Procedures
Fundamental Institutional Considerations
o Promote, passively permit or discourage use of wetlands for wastewater management
o Clarify regulatory definitions of wetland as waters of the U.S.
o Wetlands delineation and wetlands discharge definition
o Program guidance for wetlands wastewater management
Water Quality Standards Program
Current Practices
o Stream classifications and segments
o Assessment of use classification
o Establishment of criteria
o Administrative guidelines
Wetland Discharge Considerations
o Incorporation of wetland functions and values in WQS use classifications
o Parameters to support wetland uses or subcategories
o Types of criteria to support wetland parameters
o Establishment of wetland specific standards
o Designation of wetland standards
NPDES Program
Current Practices
o Permit application
o Implementation
o Effluent limitations
Wetland Discharge Considerations
o Additional permit information
o Potential effluent limitations parameters
o Techniques for determining effluent limitations
o Wetland specific permit requirements/conditions
o Permit compliance for wetlands discharges
Construction Grants Program
Current Practices
o Facilities Planning
o Operation and Maintenance
o Design
o Construction
Wetland Discharge Considerations
o Incorporation of wetland specific components
o Funding of wetlands for wastewater management
o Extent of wetlands control required for funding

Figure 3-1. Overview of Institutional Programs and Issues.

3.1 WASTEWATER MANAGEMENT PROGRAMS AND APPLICATIONS TO WETLANDS

3.1.1 Purpose and Background

Wastewater management facilities are regulated primarily by programs of the Clean Water Act. The application of these programs often is not specified and, therefore, unclear for wetlands discharges. While most wetlands are considered waters of the United States and are under the jurisdiction of the Clean Water Act, the three major programs addressing wastewater management are designed primarily for free-flowing surface waters. As a result, regulatory guidelines which address issues unique to wastewater discharges to systems such as wetlands have not been thoroughly developed.

This section describes the three major EPA programs addressing wastewater management and their relationship to wetlands discharges. Ways in which these programs might more fully address the goals of the Clean Water Act as they relate to wetlands systems also are discussed. As currently planned, updates to this chapter will be provided as clarification of policies and program requirements is achieved.

3.1.2 Wastewater Management Programs

The Water Quality Standards (WQS), National Pollutant Discharge Elimination System (NPDES) Permits and Construction Grants programs are the primary Clean Water Act programs concerning wastewater management. The WQS program is designed to protect water quality through the definition of uses and development of numerical or narrative criteria to protect those uses. The NPDES Permit program is responsible for permitting wastewater discharges to waters of the U.S. In conjunction with the WQS program, effluent limitations are established through the permitting process for each point source surface water discharge to waters of the U.S. The Construction Grants program has been the impetus for the planning, design and construction of wastewater treatment facilities under the Clean Water Act by providing federal funding for approved facilities. Figure 3-1 provides an overview of the regulatory practices relating to wetlands use for wastewater management.

3.1.3 Other Federal Programs and Policies

The programs of the Clean Water Act are the major programs affecting the use of wetlands for wastewater management. The three programs described typically are administered by the state counterparts of the EPA, as delegated by the EPA. The U.S. Army Corps of Engineers (COE) and U.S. Fish and Wildlife Service (FWS) are the other federal agencies with major wetlands responsibilities.

Some of the federal programs and policies potentially affecting wetlands management issues in addition to the three Clean Water Act programs previously discussed are:

1. Section 404, CWA (dredge & fill)
2. Fish and Wildlife Coordination Act
3. Endangered Species Act
4. Executive Order 11990 (wetlands protection)
5. Executive Order 11988 (floodplains protection)
6. EPA Statement of Policy on Protection of Nation's Wetlands.

The COE administers the Federal 404 Dredge and Fill Permit Program. The program may be delegated to the states; however, there has only been one such delegation thus far. Any action involving discharges of dredged or fill material in waters of the U.S., including wetlands, requires a 404 permit. For wastewater management, some construction activities in wetlands could require a 404 permit. The COE has issued nationwide permits which cover discharges of dredged or fill material into isolated wetlands or wetlands above the headwaters (less than 5 cubic feet per second) subject to certain conditions, size limitations and reporting requirements.

The FWS has review responsibilities for assuring wetlands and habitat protection. They also supported the wetlands classification system developed by Cowardin et al. (1979) which is widely recognized as the most comprehensive system and which has been used in the National Wetlands Inventory to delineate and map wetlands throughout the United States. The FWS actually seeks to preserve or create natural habitat and, under some circumstances, has supported wetlands-wastewater discharges to achieve these goals.

The U.S. Department of Interior has been given responsibility to identify threatened and endangered species through the Endangered Species Act. Fifteen species native to the Southeast that rely on wetlands during some part of their life cycle are listed. The act emphasizes the need to preserve critical habitats upon which protected species depend. Every state in Region IV also has a list of unique state species that are endangered, threatened or of special concern.

Executive Order 11990 was issued in May 1977 to emphasize the need for wetlands protection. Federal agencies were required to develop policies for enhancing wetlands protection and minimizing wetlands impacts. The Executive Order suggested that federal assistance or financial support be withheld from any activity not in keeping with its goals. Executive Order 11988 was issued to curtail developmental activities in floodplains. It is similar to the wetlands Executive Order in its goals and means for obtaining those goals.

The EPA policy to protect the nation's wetlands issued in 1973 recognizes the inherent values of wetlands. The policy has four major elements:

1. To evaluate a proposal's potential to degrade wetlands and preserve and protect them in decision processes
2. To minimize alterations and prevent violation of applicable water quality standards
3. In compliance with NEPA, withhold Construction Grants funds for municipal waste treatment facilities except where no other alternative of lesser environmental damage is found to be feasible
4. Advise applicants who install waste treatment facilities under a Federal grant program or federal permit to select the most environmentally protective alternatives.

Currently, EPA wetlands protection policies are being updated. The Office of Federal Activities within the EPA has convened a multi-program task force to consider further the use of wetlands for wastewater management.

3.1.4 Fundamental Institutional Considerations

Regulatory guidelines have not been developed for certain issues unique or important to wetlands systems. Further, some issues influence the interpretation or procedures of all three wastewater management programs. These issues are extremely important to the implementation and regulation of wetlands wastewater management systems and include such items as those listed below.

1. **Promote, passively permit or discourage the use of wetlands for wastewater management.**

   The lack of clear direction from EPA national program offices concerning the use of wetlands for wastewater management has resulted in some confusion. Some EPA programs discourage the use of wetlands for wastewater management. Other EPA programs actively promote the use of properly designed and managed natural and constructed wetland systems as innovative wastewater treatment alternatives. These differences in approach indicate the need for EPA to develop further and enunciate a coordinated program direction. EPA should evaluate when and how to promote, passively permit or discourage the use of wetlands for wastewater management. The Clean Water Act and associated EPA regulations need to address more clearly the use of wetlands for wastewater management to allow for greater consistency in project specific decisions.

   Because a clearly established national EPA policy is lacking, the Water Quality Standards, NPDES permitting and Construction Grants programs are not being applied consistently to wetland discharges. The resultant problems are evident at both the federal and state level. Since federal programs are being delegated largely to the states, close coordination between federal and state agencies responsible for administering programs impacting wetlands discharges is essential. In addition, better coordination between federal agencies with wetlands responsibilities will be necessary if wetlands wastewater management is to be consistent with the goals and intent of the Clean Water Act.

2. **Clarify regulatory definitions of waters of the United States related to wetlands and wastewater treatment facilities** (including wetlands treatment versus wetlands disposal).

Most wetlands are waters of the U.S. Some have interpreted this to mean that wetlands that are waters of the U.S. cannot be used for treating wastewater. Others, acknowledging the well-documented assimilative capabilities of wetlands, have promoted the use of wetlands for treatment under EPA's Innovative and Alternative (I/A) wastewater technologies program. The exact role of wetlands in wastewater management is important since the interpretation affects several permitting and funding decisions.

Several issues relate to the Clean Water Act definitions and EPA interpretations of waters of the U.S. and of wastewater treatment systems. EPA's consolidated permit regulations (40 CFR 122.3, May 19, 1980) defined many wetlands as waters of the U.S. These regulations also state that waste treatment systems (such as ponds and lagoons) are not waters of the U.S. (except where those waste treatment systems are, or were previously, waters of the U.S.). The preamble to the regulations notes that the Act was not intended to license dischargers "to freely use waters of the U.S." as waste treatment systems. These definitions made clear that treatment systems created in waters of the U.S. remained waters of the U.S. with all the protection afforded such waters under the Act.

However, on July 21, 1980, EPA's definition of waters of the U.S. was changed based on arguments that the definition was too broad. Several industry petitioners argued that the language of the regulations would require them to obtain permits for discharges into existing waste treatment systems, such as power plant ash ponds, which had been in existence for years and were originally created by impounding waters of the U.S. In many cases, EPA had issued permits for discharges from, not into, these systems. EPA reviewed the issue and then suspended the language in question based on the impoundment-ash pond issue. The wetlands issue, as a result, became unclear. As they now exist, the regulations state that wetlands are waters of the U.S. and waste treatment systems are not. This could be interpreted to mean that if wetlands were defined as part of the treatment process, they would lose their status as waters of the U.S.; a minimum of secondary treatment would not be required, nor would water quality standards need to be met. However, this interpretation does not appear to be consistent with the goals of the Clean Water Act.

Recent agency decisions have been rendered concerning the use of wetlands for treatment and the eligibility of the purchase of wetlands for federal grant funding. These decisions state that the removal of pollutants in natural wetlands is assimilation and not treatment. Therefore, if wetlands are considered to provide assimilation and not treatment, secondary treatment would be required prior to discharge to wetlands, and water quality standards would need to be met in the wetland. However, assimilation of pollutants in the wetland could be considered in meeting downstream standards.

Specific implications of wetlands being used for treatment or assimilation are related to the point of discharge for permit issuance, assigning responsibility for assuring the treatment/assimilation and determining eligibility for federal Construction Grants funding of wetland purchases. For assimilation, the point of permit would be to the wetland; the regulatory agency would be responsible for ensuring that wetland and downstream uses are maintained through permit issuance and reissuance, and Construction Grants funds would not be available for the purchase of the wetland. For treatment, however, the point of permit could be to and from the wetland; the discharger would be responsible for assuring the maintenance of the uses and functions of the wetland and in obtaining the degree of desired treatment in the wetland. In this instance, the purchase of the wetland would be eligible for funding under the Construction Grants program as part of the treatment process.

The current EPA position is that wetlands are waters of the U.S., discharges to wetlands must be permitted to the wetland, any pollutant removal is assimilation and wetlands purchase is not eligible for funding. There are some situations, however, in which the treatment capabilities of wetlands can be considered in engineering design. One example is a situation in which no nutrient criteria apply to the use classification of a wetland, but nutrient removal is important due to the nutrient sensitivity of downstream waters. In this case, nutrient removal might be a permit condition, and the system could be designed so nutrient removal is enhanced in the wetland. This situation, however, would not be eligible for Construction Grants funding.

3. Wetlands delineation and wetlands discharge definition.

Limitations in delineating wetlands and defining what is or is not a wetlands discharge affect the application of the Water Quality Standards and NPDES Permit programs to wetlands. The relationship of wetlands delineation to the WQS program stems from the need to apply a designated use and associated criteria to defined areas. Some states have adopted a wetlands-related use designation to reflect the functions and background conditions of wetlands. If all wetlands in a state were delineated, this use designation could be applied to all such areas in one administrative action. Most states do not have all their wetland areas completely delineated or mapped and, as a result, would need to designate wetlands individually as they were identified and delineated. The lack of having delineated and mapped wetlands requires site-specific standard changes for all proposed actions in wetland areas. Administratively, this is burdensome and the value of establishing wetlands-related use designations or use subcategories is diminished. Some states have found that having a wetlands use designation or subcategory at least highlights the differences in wetland systems and provides guidelines for the application of site-specific standards.

Defining a "wetlands discharge" is also important to administering wetlands-related guidelines. Currently, no clear method exists for defining when a discharge is a wetlands discharge. As a result, applying wetlands-specific guidelines is difficult. This issue will become more important if wetlands-related standards or protective guidelines are adopted. Procedures for differentiating between discharges to wetlands and other surface waters would be helpful. This is an important step in assuring that wetlands discharges are properly considered and, if feasible, properly designed, implemented and monitored.

Wastewater discharges can enter wetlands by three primary pathways:

1) Waters upstream from the wetland
2) Overland flow to the wetland
3) Direct discharge into the wetland.

Defining direct discharges to wetlands is straightforward. Overland flows to wetlands are a little more difficult to classify. A small land buffer used primarily to achieve uniform sheet-flow to the wetland should be considered a wetlands discharge since the overland flow component acts only as a discharge mechanism to the wetland. If a sufficient land area is allocated to provide treatment prior to entering a wetland, the overland flow system would be considered part of the treatment process. The determination of whether this is a wetlands discharge might then depend on soil type, slope and other variables (such as vegetation) that affect the movement and amount of water flowing into the wetland. Situations where a high proportion of the wastewater enters the wetland and potentially affects wetland uses should probably be considered a wetlands discharge.

Even more ambiguous are discharges to upstream surface waters that flow through the wetland. Where is the demarcation line determining whether the discharge should be considered a wetlands discharge? Due to variations in flows and flow patterns, establishing an arbitrary distance upstream from a wetland is not feasible. Two methods that might be useful involve identifying: 1) impacts from hydraulic loading and 2) relationship to the dissolved oxygen sag. A combination of both approaches might be reasonable as well. When evaluating impacts from hydraulic loading, the main criterion would be the percentage of flow in the wetland attributable to the wastewater. If the wastewater will cause a significant increase in water depth in the wetland or a significant impact on hydroperiod, it may be appropriate to evaluate such a discharge as a wetlands discharge.

Relating the definition to the position of the dissolved oxygen sag would be appropriate only when a definable channel which can be modeled flows directly into the wetland. In this situation, if the wetland lies below the point of recovery from the DO sag, the discharge **would not be** considered a wetlands discharge under most circumstances. Exceptions would be when: 1) the hydraulic loading factor is important or 2) when nutrients or other constituents are addressed by standards in downstream waters (in this case, the wetland). If the wetland lies at or upstream from the predicted DO sag recovery point, the discharge **would be** a wetlands discharge. Situations where the channel does not intersect the wetland or where flows stay within the channel except during peak flood conditions probably should be excluded from this approach.

4. Program guidance for wetlands wastewater management.

Regulations and guidance for EPA's three major wastewater management programs (Water Quality Standards, NPDES Permit and Construction Grants) are primarily designed for facilities discharging to free-flowing streams and rivers, lakes and estuaries. As a result, program guidelines typically are not appropriate for wetlands wastewater management alternatives and need refinement. Specific standards, permits and grants issues for which program guidelines would prove valuable are discussed in Sections 3.2, 3.3 and 3.4 of this chapter.

3.1.5 Existing State Policies/Programs

This section summarizes the policies and programs of each state concerning the use of wetlands for wastewater management. Subsequent sections of this chapter describe state practices as they relate specifically to the three wastewater management regulatory programs.

Alabama. The state of Alabama does not have an explicit nor separate policy regarding the use of wetlands for wastewater management. The potential use of wetlands for treatment of effluent is not officially recognized. The Alabama Department of Environmental Management (ADEM) has the administrative authority for the NPDES permit program. ADEM does not, however, distinguish wetlands from other waters of the state. Wetlands are delineated and defined by ADEM using the Corps of Engineers definitions in conjunction with Section 404 of the Clean Water Act (dredge and fill) permitting activities. Wetlands definitions and mapping programs have been undertaken in recent years in the coastal areas (Alabama Marine Environmental Consortium), the Gulf Rivers Basin and the Alabama River Basin (USDA Soil Conservation Service) and the Tennessee-Tombigbee Waterway (National Wetlands Inventory) in response to other resource management needs.

The ADEM is responsible for setting the monitoring requirements of each discharge. These monitoring requirements may vary according to specific conditions at each discharge. For most discharges, flow, pH, dissolved oxygen, biochemical oxygen demand, suspended solids and ammonia are monitored. Other parameters may be required at the discretion of the ADEM. Alabama regulations recognize that because of natural conditions in wetlands, state water quality criteria may not be met. Exceptions in these cases may be granted for dissolved oxygen and pH limits.

Florida. The state of Florida has provided for specific modifications and exemptions to the State Water Quality Standards in order to permit and manage wetlands discharges. Recently, legislation was passed to enable state regulatory agencies to consider the use of wetlands for wastewater treatment.

By state law, wetlands are considered waters of the state and under the jurisdiction of the Florida Department of Environmental Regulation (FDER). To distinguish between upland areas and wetland waters of the state, FDER has developed a wetland vegetation index. This index also is used in some cases to determine the landward extent of the "waters of the state" and, thus, the jurisdictional boundaries of FDER.

Florida, differing from other Region IV states, has **non-jurisdictional wetlands** which are not considered waters of the state. These are wetlands that: 1) are entirely confined on privately owned lands and 2) have no connections to downstream waters or groundwater. These wetlands, however, still may be considered waters of the U.S., and if so would be regulated as such. Although new regulations increase state jurisdictional waters based on vegetation, the difference between state and federal jurisdiction should be addressed.

When compared with other Region IV states, Florida has much greater areas of wetlands mapped and classified. This data base provides a good foundation for describing the various wetland types in Florida. In December 1984, a map of Florida wetlands became available through the U.S. Fish and Wildlife Service.

Generally, wetlands contiguous with another body of water are considered as part of that water body and subsequently are assigned the same water quality standards as the "parent" water body. If waters do not meet criteria due to natural conditions (low DO or pH, for example), Section 17-3.031 FAC provides for site-specific alternative criteria. These criteria offer a permanent relief mechanism for a given set of background conditions.

Exceptions to existing criteria also are granted for experimental use of wetlands for recycling effluent. Thus, under certain conditions wetlands can be used for further treatment of effluent beyond secondary. These experimental uses of wetlands are designed to evaluate the feasibility of wetlands use and to develop proper guidelines for effluent discharges to wetlands. Requirements for such experimental uses are generally more comprehensive than that required for ordinary discharges.

Monitoring requirements vary from site to site and may include the usual parameters (pH, DO, suspended solids, etc.) in addition to other parameters such as chloride, sulfate, benthic macroinvertebrates, vegetation surveys or annual aerial infrared photography.

Predictive modeling is not used by FDER to assess the potential impacts of wastewater discharges on wetlands and to set permit limits. Where ambient conditions warrant site-specific criteria or special exemptions, baseline water quality studies are used to determine appropriate critiera.

Legislation passed in 1984 requires that wetlands be considered for their potential in "treating" wastewater (Section 17-3 FAC). Rules are being established in response to these questions and should be adopted during 1985. Issues concerning wetlands standards and discharge requirements also are being addressed.

Georgia. The Georgia Environmental Protection Division (EPD) does not define or distinguish wetlands from other waters of the state for the purpose of permitting wastewater discharges.

The Georgia EPD does not have an official policy concerning the discharge of treated wastewater to wetlands. Provisions are made within the Georgia Water Quality Regulations for certain natural water conditions which may not be within criteria. The regulation allows for "alternative effluent limits" to be established for such waters.

The water quality criteria and permit limitations for wetlands discharges usually are established on a case-by-case basis. In setting effluent limitations for wetlands discharges, the Georgia EPD generally does not use predictive modeling; instead, it relies on site analysis and qualitative judgements. Swamp creeks sometimes are modeled if a definable channel exists. The greatest concern for setting effluent limits involves the low flow swamp streams of southern Georgia. Consistent decisions regarding modelable versus non-modelable streams and reproducible field survey results are of related interest. Monitoring requirements for wetlands discharges do not generally differ from other wastewater discharges in Georgia.

Kentucky. Water quality programs in Kentucky are administered by the Kentucky Division of Water (KDOW). Although KDOW does not differentiate wetlands from other waters of the Commonwealth for the purposes of permitting effluent discharges, wetlands are classified and identified by the Kentucky Department of Fish and Wildlife using the USFWS classification system. Mapping of wetlands generally has been done in conjunction with surface mining reclamation studies.

Since wetlands are not distinguished from other waters of the Commonwealth, a specific policy concerning wastewater discharges to wetlands has not been developed by the KDOW. Kentucky Environmental Law provides for a variance of criteria to account for natural background conditions, and the Waste Discharge Law provides for special considerations for effluent monitoring requirements should the need arise. KDOW has indicated that stream segments characterized as marshes are assumed to respond as natural channels under critical flow conditions. In any case, determinations of appropriate criteria are made on a case-by-case basis and are subject to review every three years.

Mississippi. In Mississippi wetlands are considered waters of the state. The Mississippi Bureau of Pollution Control (MBPC) defines and delineates wetlands using COE definitions and maintains jurisdiction over these waters, except those which are wholly landlocked and privately owned. The MBPC, however, does not distinguish wetlands from other waters of the state for the purposes of permitting wastewater discharges.

The MBPC requires a minimum of secondary treatment for discharges to waters classified as "Fish and Wildlife." Wetlands most frequently are classified for fish and wildlife. When determining appropriate criteria for wetland discharges, the MBPC considers uses and whether the wetland is isolated or contiguous to other state waters. Wasteload allocation and effluent limitations for wetlands discharges are established in the same manner as are other non-wetland discharges. Where distinct channels or discernable flows are observed, stream models generally are applied to obtain effluent limitations. In some wetlands, particularly the oxbow wetlands, a model is not applied, but on-site biological assessments are made that include factors such as size and type of wetland and potential for eutrophication problems. No special monitoring requirements are applied to wetlands discharges, but MBPC may exercise discretion in this area.

North Carolina. The North Carolina Division of Environmental Management (NCDEM) recognizes wetlands as unique and specific water bodies. Extensive water body segments have been classified as Swamp Waters, especially in the Coastal Plain, for the purpose of applying appropriate water quality standards. Swamp Waters are defined as waters having "low velocities and other natural characteristics which are different from adjacent streams." Designation of a stream segment as Swamp Waters, therefore, does not require a stream segment to be dominated by acknowledged wetlands.

The NCDEM does not have a specific policy to encourage or prohibit wastewater discharges to wetlands. The NCDEM has permitted several "wetlands discharging systems." These systems are being designed to utilize the assimilative capacity of the wetland through a diffuse outfall, while maintaining wetland functions and values. Professional judgement has been used to determine effluent limits for unmodelable systems, with the aid of a site visit and field work. To date, secondary limits have been assigned to all designated wetlands discharging systems.

The NCDEM is considering a policy requiring a freeze on designating wetlands discharging systems. During this period, the NCDEM will research and review existing wetlands dischargers. Wetlands are not allowed to be considered as treatment or buffering devices.

South Carolina. The South Carolina Department of Health and Environmental Control (DHEC) has jurisdiction over waters of the state, including wetlands. Swamp waters specifically are defined for the purpose of assigning wasteload allocations and permitting wetland discharges. Wetlands discharges are distinguished from other wastewater discharges, and DHEC has specifically developed a policy concerning permitting and setting wasteload allocations for wetlands discharges.

Wetlands discharges currently are authorized only as a last resort, when there are no other reasonable alternatives. Additionally, DHEC advises that wetlands used should be owned by the discharger or that an easement should be required. Although specific water quality standards have not been established for wetlands, separate numeric or narrative criteria may be established for waters with natural characteristics outside established limits. Specific exceptions may be made in Class A (direct contact) and Class B (fish and agricultural) waters, where natural conditions have lowered dissolved oxygen and pH levels.

The policy adopted by DHEC for developing wasteload allocations recognizes that waters vary in their ability to assimilate nutrient loadings; that it is difficult to define average water quality conditions in wetlands, and that the predictive capability in estimating assimilative capacity in these waters is poor. At a minimum, DHEC requires secondary treatment for publicly owned treatment works and Best Available Treatment (BAT) for privately owned treatment works. A site investigation of the proposed wetlands discharge is recommended to determine if modeling techniques can be applied. Nutrient loadings and specific nutrient standards for these waters must be addressed on a case-by-case basis.

Tennessee. The state of Tennessee does not have a specific policy or regulatory practice relating particularly to wetlands discharges. Discharges are permitted to wetlands under the same conditions as are discharges to other waters of the state. Wetlands have been mapped by the FWS and COE agencies. Of great concern to the state is the 404 permitting process and which wetlands fall under those jurisdictional limits.

When treatment beyond secondary is required, a modified Streeter-Phelps equation is utilized to assist in determining wasteload allocations if there is a discernable channel. Low flow conditions are modeled, and overbank flooding to associated wetlands is ignored. Where the flow is slow or nonexistent, or when a distinct channel is not distinguishable, a lake model is used.

Permit requirements may be modified for dissolved oxygen levels on a case-by-case basis if natural conditions warrant such decisions. No specific monitoring requirements have been established for wetlands discharges in Tennessee.

Recently, attention has been given to maintaining and managing wetlands which could affect wetlands-wastewater discharges. A draft Governors Executive Order on Wetlands Maintenance and Management stresses the need for wetlands protection, particularly due to wetland losses and degradation over the years. Every aspect of wetlands activities from recreation to construction would be addressed by the Executive Order and regulatory mechanisms. Specifically, use of wetlands for "effluent and solid waste dumping" would be discouraged. If adopted as such, the Executive Order and other regulatory guidelines could influence whether or how wetlands are used for wastewater management. Guidelines have also been proposed for identifying wetlands for regulatory purposes.

3.1.6 Local Regulatory Responsibilities

In addition to federal and state practices and policies, certain local considerations must be recognized. The implementation of wetlands discharges may be encouraged or discouraged at the local or regional level. Activities in some wetlands may be limited because of the restrictive or jurisdictional powers of local agencies or organizations.

Agencies with planning and land use functions have significant ability to control land use decisions. Site-specific rulings or blanket ordinances may restrict activity via flood plain ordinances. Some localities have city, county or regional wetlands protection laws that may make wetlands utilization for other than preservation oriented uses an impossibility. The flexibility of such ordinances varies as does the authority of local commissions and planning groups.

Although coastal commissions usually are concerned with saltwater marshes, they sometimes have jurisdictional powers over freshwater wetlands adjacent to saltwater wetlands. In these cases, approval would be needed from the commission for a wetlands discharge.

Utility companies are also in a position to limit wetlands utilization for wastewater discharge. In one instance, a proposed wetland treatment system for a new subdivision in Florida was considered feasible from a technical standpoint. The local water and sewer authority, however, would not grant a building permit to the subdivision unless they agreed to utilize both water and sewerage services supplied by the authority. Since the community was committed to centralized sewerage in order to build, the wetlands option was no longer feasible from an institutional standpoint.

In the instance where federal funds may be involved in financing part of a wetlands discharge, local opinions expressed at public hearing on these matters may influence the feasibility of a wetlands discharge.

3.2 WATER QUALITY STANDARDS PROGRAM

3.2.1 WQS Purpose and Background

The purpose of the Water Quality Standards Program (40 CFR 131) is to: (1) protect the public health and welfare; (2) enhance the quality of waters of the U.S.; (3) provide sufficient water quality for the protection and propagation of fish, shellfish and wildlife, recreation in and on the water, agricultural and industrial purposes, and navigation, and (4) specify uses and appropriate numeric or narrative water quality criteria which establish water quality goals for a specific water body. Water quality standards serve as the regulatory basis for establishing controls on treatment processes, beyond secondary treatment, necessary to support designated uses.

Stream segments are delineated and associated use classifications are established as part of a state's Water Quality Standards Program. Water quality criteria then are established to assure that designated uses will be maintained and protected. Uses and criteria are the two components of water quality standards. States set water quality standards and review them triennially. EPA reviews the state adopted standards and may promulgate federal standards where the state fails to correct inadequacies or where necessary to serve the purposes of the Clean Water Act.

Effluent limitations are established for each wastewater management facility that discharges to waters of the U.S. to meet established water quality criteria. Typically, receiving waters are classified as effluent- or water quality-limited. An effluent-limited segment describes a receiving water body where water quality standards will be met if Publicly Owned Treatment Works (POTWs) provide secondary treatment of effluent. A water quality-limited segment occurs when standards will not be met by POTWs providing secondary treatment alone, necessitating implementation of more advanced treatment controls or strategies.

Revisions to the water quality standards regulations were made in November 1983 (40 CFR 131). These regulatory revisions and associated handbooks provide increased guidance for determining use attainability, utilizing site-specific criteria, applying an anti-degradation policy, varying (upgrading or downgrading) levels of aquatic protection and applying general policies on mixing zones and variances.

The current water quality standards regulations do not establish specifically a rigid procedure for the technical review and revision of water quality standards. Specific procedures are left to the discretion of the individual states. The requirements of the federal regulations provide a general procedural framework based on the allowable considerations for the revision of water quality standards.

Key decision points in Figure 3-2 focus on use attainability, natural background conditions, site-specific or generic criteria, variances and antidegradation/protection of downstream uses. Each of these points is discussed individually in the following sections.

Use Attainability. A major emphasis in the standards review process is placed on the attainment or attainability of the water body's designated use as well as ensuring that the highest attainable use is designated. The 1983 revisions include increased guidance for determining appropriate application of use attainability studies. The determination of the appropriate use classification, use-attainability studies and the subsequent assignment of water quality criteria may have important implications for the use of wetlands for wastewater management.

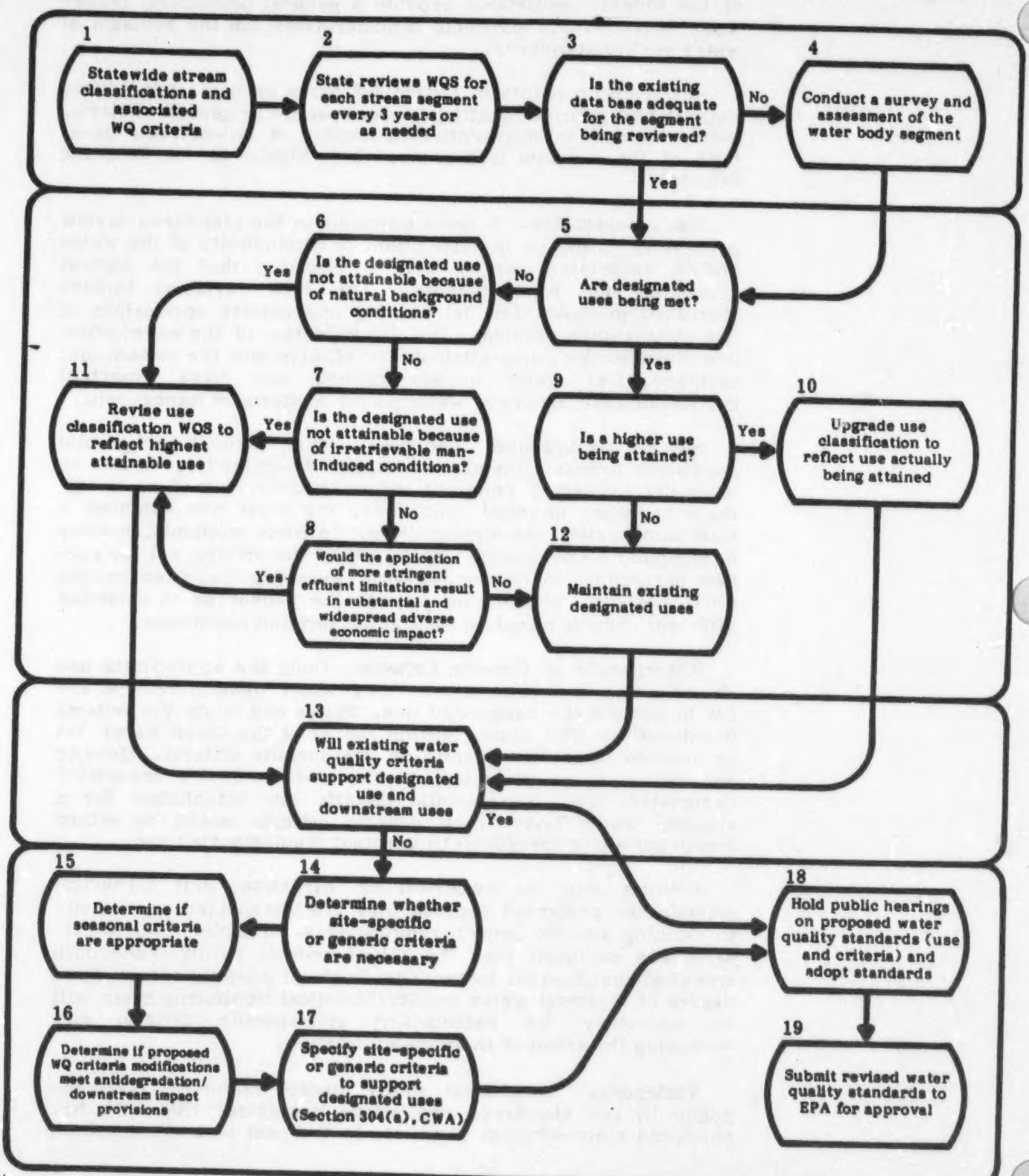
Natural Background Conditions. When natural background conditions preclude the attainment of a designated use either by naturally occurring pollutant concentrations, low flow conditions or other physical conditions, the state may establish a more appropriate use classification. In many wetlands, natural background water quality may be below the criteria set for certain parameters in flowing streams, including dissolved oxygen (DO) and pH. Regulations provide the mechanism to establish different criteria based on natural background conditions.

Site-specific or Generic Criteria. Once the appropriate use classification has been determined, water quality criteria are set to protect the designated use. States can apply the criteria developed by EPA under Section 304(a) of the Clean Water Act or develop their own generic or site-specific criteria. Generic criteria apply to all waters in the state with the associated designated use. Site-specific criteria are established for a specific water body when generic criteria would be either inappropriate or insufficient to protect the designated use.

Criteria may be numerical or narrative, but numerical criteria are preferred because they are interpreted more easily in defining specific control requirements. Establishment of criteria less stringent than the 304(a) criteria requires adequate technical justification to the EPA Regional Administrator. Some degree of instream water quality/biological monitoring often will be necessary for establishing site-specific criteria and reviewing the effect of their implementation.

Variances. A general water quality standards variance policy in the standards regulations recognizes that EPA has approved state-adopted variances in the past and will continue

Figure 3-2. Overview of the Water Quality Standards Program.


1
Statewide stream classifications and associated WQ criteria
2
State reviews WQS for each stream segment every 3 years or as needed
3
Is the existing data base adequate for the segment being reviewed?
No
4
Conduct a survey and assessment of the water body segment
Yes
5
Are designated uses being met?
No
6
Is the designated use not attainable because of natural background conditions?
Yes
No
Yes
7
Is the designated use not attainable because of irretrievable man-induced conditions?
Yes
No
8
Would the application of more stringent effluent limitations result in substantial and widespread adverse economic impact?
Yes
No
9
Is a higher use being attained?
Yes
No
10
Upgrade use classification to reflect use actually being attained
11
Revise use classification WQS to reflect highest attainable use
12
Maintain existing designated uses
13
Will existing water quality criteria support designated use and downstream uses
Yes
No
14
Determine whether site-specific or generic criteria are necessary
15
Determine if seasonal criteria are appropriate
16
Determine if proposed WQ criteria modifications meet antidegradation/ downstream impact provisions
17
Specify site-specific or generic criteria to support designated uses (Section 304(a), CWA)
18
Hold public hearings on proposed water quality standards (use and criteria) and adopt standards
19
Submit revised water quality standards to EPA for approval

to do so under certain conditions. Each variance is to be included as part of the water quality standard and is subject to public review, as are other standards changes. Each variance is to be based on demonstrating that meeting the standard would cause substantial and widespread economic and social impact. The application of a water quality standards variance to a wetland alternative, although possible, does not address the primary issue of potentially inappropriate use and criteria designations due to natural conditions.

Antidegradation. The underlying objective of the Clean Water Act (CWA) is to restore and maintain the chemical, physical and biological integrity of our nation's waters. A specific goal of the CWA is to achieve, where attainable, that level of water quality which provides for the protection and propagation of fish, shellfish and wildlife and provides for recreation in and on the waters of the U.S. Accordingly, water quality standards regulations require states to develop and adopt a state-wide antidegradation policy. It is the purpose of this policy to assure that existing instream uses and the level of water quality necessary to protect those uses are maintained and protected. Existing uses are defined as those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards. States must determine the existing uses of their waters and the level of water quality necessary for their protection.

Each situation should be considered on its own merits. Where significant resources are involved and a significant degree of uncertainty exists regarding the success of maintaining a use, regulators should assure protection of the existing use. Where irreversible or irretrievable commitments of resources would be involved, erring on the side of protecting existing uses is appropriate (EPA 1984a).

Since most wetlands are waters of the U.S., they are afforded protection under the anti-degradation policy. The existing uses of a wetland or of downstream waters should, therefore, not be altered by a wastewater discharge. Since a wetland's natural processes may affect or determine an existing use, alterations to natural processes that change existing uses may not be allowable based on the state's antidegradation policy.

3.2.2 WQS Program Requirements and Current Practices

EPA directs and administers the standards program through the EPA regional offices. EPA Regional Administrators have the authority to review and approve state standards in accordance with national policies and guidelines; however, each state has the responsibility of developing its own standards.

The WQS program has many facets, as is indicated by Figure 3-2. Some elements of the program can be directly applied to wetlands discharges, while adaptations are required for other program elements due to the nature of wetlands. Those elements requiring clarification are discussed in detail in Section 3.2.3. Current program requirements and state practices provide the framework for assessing additional considerations.

The steps outlined in Figure 3-2 are procedures that should be followed for assessing water quality standards in any stream segment. Note the two distinguishing parts of the program, uses and criteria, that form water quality standards. Each state has defined different use classifications, as shown in Table 3-1. Once uses are defined and approved through the public hearing process, they become part of the standards program. Numerical or narrative criteria are then adopted for the identified uses. Typically, criteria are defined for the following water quality indicators: dissolved oxygen, pH, water temperature and fecal coliforms. Sometimes organic, nutrient or toxic parameters are specified as well.

In practice, the WQS program has four major components represented by Figure 3-2. Activities one through four involve establishing stream classifications and segments and reviewing their standards. Activities 5 through 12 assess the attainment and potential change in use classification for a stream segment. Activities 13 through 17 establish criteria to protect identified uses. Finally, activities 18 and 19 are the administrative requirements necessary to implement a change, including the public hearing process. These are the procedures Region IV states followed prior to recent revisions to the WQS program. Most likely they will be the procedures followed in the near future as well. The potential implications of the revisions on wetlands discharges will be discussed in Section 3.2.3.

Typically, wetlands in each state fall under the standards associated with the adjacent water body, commonly classified fish and wildlife. A specific wetland type could be required to meet different criteria within a state and between states, however, depending on adjacent water body classifications and differences in associated water quality criteria. As a result, criteria for wetlands based on adjacent water bodies can be insensitive to inherent differences in wetland types. Most states are now assessing wetlands criteria on a site-specific basis when a wetlands discharge is considered. Florida water law provides guidance for setting site-specific criteria for stream segments where existing criteria are not appropriate nor protective of the designated use classification. North Carolina has a specific "swamp" designation, or subcategory, which allows for pH and DO criteria to based on natural, background conditions. Such a designation provides greater flexibility in water quality standards for segments with significantly

Table 3-1. State Water Use Classifications

Alabama
Public Water Supply
Swimming and Other Whole Body Water Contact Sports
Shellfish Harvesting
Fish and Wildlife
Agriculture and Industrial Water Supply
Industrial Operations
Navigation

Florida
Class I: Potable Water Supplies
Class II: Shellfish Propagation or Harvesting
Class III: Recreation, Propagation and Management of Fish and Wildlife
Class IV: Agricultural and Industrial Water Supply
Class V: Navigation, Utility and Industrial Use

Georgia
Class A: Drinking Water Supplies
Class B: Recreation
Class C: Fishing, Propagation of Fish, Shellfish, Game and Other Aquatic Life
Class D: Agricultural
Class E: Industrial
Class F: Navigation
Class G: Wild River
Class H: Scenic River
Class I: Urban Stream

Kentucky
Aquatic Life
1. Warm water aquatic habitats
2. Cold water aquatic habitats
Domestic Water Supply Use
Recreational Waters
1. Primary contact
2. Secondary contact
Outstanding Resources Waters

Mississippi
Public Water Supply
Shellfish Harvesting Areas
Recreation
Fish and Wildlife
Ephemeral Stream

North Carolina (fresh surface waters only)
Class A-I: Source for drinking, culinary and food processing purposes (uninhabited watersheds)
Class A-II: Source for drinking, culinary and food processing purposes
Class B: Bathing and any use except A-I or A-II
Class C: Fishing, boating, wading and any use except B, A-I or A-II

South Carolina (fresh waters only)
Class AA: Waters suitable for domestic and food purposes or waters which are an outstanding recreational or ecological resource
Class A: Waters suitable for direct contact use
Class B: Waters suitable for domestic supply after conventional treatment, for propagation of fish, industrial and agricultural use and other uses requiring lesser quality

Tennessee
Domestic Raw Water Supply
Industrial Water Supply
Fish and Aquatic Life
Recreation
Irrigation
Livestock Watering and Wildlife
Navigation

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[1] North Carolina has subclasses for nutrient sensitive waters, trout and swamps.

different natural or background conditions. Subcategories can be adopted through the triennial review process or on an as-needed basis. Specific water quality criteria associated with these subclasses can be based on documented natural levels.

The eight Region IV states administer the WQS program in different ways, particularly for wetlands discharges. Table 3-2 summarizes state water quality standard procedures for wetlands discharges in relation to wetlands use classifications, use attainability for wetlands discharges, criteria for wetlands discharges and modified standards criteria for wetlands. State agencies currently are utilizing only a few of the procedures available to them under the WQS program. The use of other procedures for assessing or administering a potential wetlands discharge is presented in the next section.

One administrative consideration of the WQS program encountered by each state is the need for a public hearing for changes in water quality standards. This means that with current program policies, a public hearing and the associated administrative requirements would be required for any wetlands discharge. Administratively, this is cumbersome and may act to discourage wetlands use. On the other hand, the current system was designed to protect waters of the U.S. from inappropriate use. Some of the alternatives suggested in the following section are intended to provide a means for balancing the administrative and protective requirements of the WQS program.

3.2.3 WQS Wetland Discharge Considerations

Legitimately, the question can be asked, "What makes wetlands different from any other type of aquatic system?"; and, therefore, "Why do wetlands require distinct regulatory guidelines?" In response, the following should be noted:

1. Wetlands are different from most aquatic systems due to their nature as a transition between fully terrestrial and fully aquatic systems.

2. During the past ten years, the values and functions of wetlands have been recognized not only for their ecological value, but also for their benefit to society.

3. Wetlands systems are often hydrologically sluggish in comparison to free-flowing waters and have different water quality requirements for maintaining their functions and values.

4. Wetlands were not the prototype system used when wastewater management-related regulatory guidelines were adopted under the Clean Water Act. Regulatory clarifica-

Table 3-2. Summary of Current State Practices Associated with the WQS Program.

State	Has use-classification for wetlands? Activity 1	Has adopted additional uses that are unique to wetlands? Activity 2,11	Has used use-attainability in conjunction with a wetlands discharge? Activities 11,13	Specifically acknowledges use of wetlands for WWM? Activities 1, 13	Has criteria for wetlands discharges? Activity 13	Has modified standards criteria for wetlands due to natural conditions? Activities 14,15,17
Alabama	-	-	-	-	-	-
Florida	-	-	-	X[2]	X[2]	X
Georgia	-	-	-	-	-	X
Kentucky	-	-	-	-	-	-
Mississippi	-	-	-	-	-	-
North Carolina	X	-	X	-	-	X
South Carolina	X[1]	-	-	-	-	X
Tennessee	-	-	-	-	-	-

[1] Had a "natural waters" use modifier which was rescinded recently.

[2] Florida acknowledges "experimental" uses of wetlands for wastewater discharges; recent regulatory changes will lead to rules specifically governing the use of wetlands for wastewater management.

tion or program guidance is needed to adequately address wetlands use.

In the case of wetlands used for wastewater management, two essential elements must be balanced and considered in developing regulatory guidelines: protection and use. Neither area is considered fully by current guidelines. One important distinction should be noted concerning the word "use." Section 303(c) of the Clean Water Act mentions several "uses." While the statutory listing of uses is not a limitation, EPA does not recognize waste transport as a beneficial use. When wetland protection and use are discussed, "use" refers to the inherent functions and values of wetlands.

If wetlands are to be used as part of wastewater management systems, their uses must be fully identified and protected. Wetland-specific regulatory guidelines are needed to accomplish this. Even though waste transport cannot be a classified use for waters of the U.S, wetlands can be used for wastewater management as long as the identified beneficial uses incorporated into the use classifications and existing uses are protected.

Preeminent to water quality standards issues is the **extent of acceptable change in the wetland.** This is one of the major issues that must be addressed in assessing a potential wetlands project. Not only is this important in helping to define potential impacts from a discharge, but it is also important in assessing the long-term potential of using a wetland. From a wastewater management perspective, the latter assessment is dependent on the objectives of wetlands use (i.e., treatment or disposal) and the sensitivity of a wetland to change from hydrologic or water chemistry alterations.

Experience from existing discharges indicates that although a wetland's functions and values may be primarily maintained, changes will occur as a result of a wastewater discharge. If the objective is to maintain a wetland just as it is, or at least to allow it to go through successional changes naturally, that wetland should not be used for a continuous wastewater discharge. Potentially, however, a wetland receiving only a seasonal discharge (aligned with the wetland's natural hydroperiod) at a low discharge rate (e.g., under 1.0 inch/week) would experience few changes. But for the vast majority of practical applications of a wetlands discharge, alterations in the existing vegetation assemblage, hydrology and water chemistry should be expected.

The question is, then, "How much change is acceptable?" Water quality standards criteria, in essence, define the amount of acceptable change for those water chemistry parameters identified by the standards program. But unless water quality standards are expanded, the extent of acceptable change in many wetland parameters will not be defined. Parameters in this category include vegetation assemblages, hydrology and some water chemistry parameters. Guidelines concerning acceptable change should be addressed through the Water Quality Standards program. If modifications to the WQS program are not forthcoming, the determination of acceptable change could be established through the NPDES Permit process by permit conditions, performance criteria or states' anti-degradation policies. Regardless, the final decision of how much change is acceptable remains subjective.

An important concept relating to changes in wetlands is the **variable advancing front or zone of impact.** This recognizes that wetland changes resulting from wastewater will not be uniform, but will progress down gradient from the point of discharge. Water quality will change down gradient; for example, nutrients and metals are removed, DO levels decrease and recover, pH is buffered and bacterial indicators die off. Some changes result from dilution or base flow down gradient. Vegetation impacts and stimulation vary as the wastewater moves away from the point of discharge. Species shifts can range from slight to extensive. In essence, changes do not occur uniformly, but at variable distances from the discharge and at various times. As the discharge continues, this zone of influence where change occurs advances away from the discharge point. Stabilization continues where change already has occurred. The variable zone of influence not only affects the discussion of the extent of change, but also planning and design decisions concerning the size of wetland needed and loading rates.

To many wetlands specialists, the idea of change in the wetland is not in itself alarming. Many believe that properly managed change can be positive (e.g., vegetation types that provide better habitat, hydrologic modifications that re-establish diminished flows). A negative change is perceived primarily to be associated with a complete change in the system (e.g., from a wooded system to a marsh or from sheet flow to channelized flow). The functions and values of a wetland must be understood as a basis for selecting a wetlands site. Choosing unique, highly sensitive or pristine wetlands should be avoided. Changes also should be avoided in wetlands providing well-defined, beneficial functions if the potential changes will diminish the ability of the wetland to perform that function.

The degree of acceptable change is defined or measured by several factors, some outlined by regulatory programs and some left to judgement. The latter should be made as objectively as possible; one must understand the functions and values of a particular wetland, and addition of wastewater will lead to some changes. If changes are not desired, a discharge should be avoided. If such changes are considered acceptable, changes should be managed as much as possible; and it should be understood that the exact type and extent of change is difficult to predict. Two options exist for dealing with changes to a wetland: let the changes follow a "natural" course or manage the changes to optimize assimilation, habitat, etc. Chapter 7 discusses some of the management options available and Chapter 8 summarizes the types of wetlands impacts resulting from wastewater discharges.

To be responsive to the regulatory questions concerning wetlands use, several considerations (which are related to the activities from Figure 3-2) should be addressed by the WQS program for wetlands discharges. These include:

1. **Incorporation of wetland functions and values into water quality standards use classifications**
2. **Parameters to support wetland uses or subcategories**
3. **Types of criteria to support wetland parameters**
4. **Establishment of wetland specific standards**
5. **Designation of wetland standards.**

Most of these considerations apply to the early stages of the water quality standards review process when assessing the classification of stream segments and adequacy of use designations, or toward the end of the process when evaluating the adequacy of criteria to protect uses. An evaluation of each of these WQS program considerations is presented in the following section.

3.2.4 Alternatives for WQS Wetland Discharge Considerations

To enhance the protection afforded wetlands by the Clean Water Act, modifications to the Water Quality Standards program may be necessary. These changes could also improve the consistency in interpreting how the Program is applied to wetlands. The major considerations suggested involve use classifications and associated protective criteria.

Consideration 1--

Incorporation of Wetlands Functions and Values into Water Quality Standards Use Classifications. Currently, many wetland functions and values are not protected by existing use classifications. The common uses discussed in the CWA include: public water supplies; protection and propagation of fish, shellfish and wildlife; recreation; agricultural and industrial water supplies, and navigation. Table 3-3 indicates how, if at all, these common use classifications relate to the primary wetland functions and values. Some can be categorized under a typical use classification. Even when this is possible, however, wetland specific values must be acknowledged and incorporated into the decision making process if the WQS program is to consider and protect wetlands appropriately.

Table 3-3. Comparison of Commonly Identified Wetlands Functions and Values with Use Classifications

Wetland Function/Value	Relationship to Water Quality Standards Use Classifications
Storm Buffering	-
Water Storage	-
Water Purification	-
Natural Resource Extraction	-
Groundwater Recharge	-
Nutrient/Material Cycling	-
Aesthetics	-
Habitat	Protection and propagation of fish and wildlife
Protected Species	Protection and propagation of fish and wildlife
Recreation	Recreation

A new use classification or a subcategory of an existing use are options for addressing the important wetland uses not defined by existing categories. Storm buffering, water storage, groundwater recharge and material cycling are valuable uses that could comprise a new category or subcategory. This could be combined to form a collective, broader use category or could individually be the basis for protecting specific uses. Each of these uses has a direct relationship to water quality in a wetland and, importantly, to uses and water quality downstream from the wetland. Criteria delineating the parameters that help define and protect these uses could be either narrative and numeric.

How does a new use classification or subcategory relate to the use of wetlands for wastewater management? First, it would acknowledge that some wetlands do not or cannot support a level of water quality to provide for the protection and propagation of fish, shellfish and wildlife and recreation in and on waters of the U.S. some or all of the time in their natural state. Their condition needs to be protected, yet approached from a different perspective. A wetlands related use classification or subcategory would acknowledge and protect the inherent values of wetlands not relating to existing use classifications. Criteria might be significantly different than those for fish and wildlife or recreation. Second, wastewater discharge loadings might be assessed differently if criteria more realistically related to the actual uses and water quality conditions of a wetland.

The natural waters clause present in the WQS regulations of most states is a method of addressing the inherently different qualities or background conditions in wetlands. Sometimes the water quality levels required by standards criteria cannot be met in a water body due to natural conditions. This discrepancy can be addressed by invoking the natural waters clause. In this situation, site-specific criteria are required, but the administrative actions typically required of a site-specific standards change is not necessary.

The following options are available for addressing the considerations of incorporating wetland functions and values into water quality standards use classifications.

- Adopt a new WQS wetland use classification that broadly addresses all wetland functions and values.

  Significant Features
  - Requires a WQS change
  - May be too broad by addressing some uses already covered by existing use classification
  - Could address the issue in one administrative action
  - Could add a significant level of wetlands protection
  - Could improve procedures for evaluating wetlands
  - Could be difficult to implement

- Adopt new use classifications based on specific uses that are not currently protected for wetlands (e.g., flow regulation, water purification).

  Significant Features
  - Requires a WQS change
  - Could address the issue in one administrative action
  - Could be applied to numerous types of water bodies
  - Could improve procedures for evaluating wetlands
  - Could have significant implications to other waters
  - Questions may exist regarding the applicability of the CWA to the protection of these uses

- o Use wetland subcategories under existing use classifications.

  Significant Features
  - Requires a WQS change
  - Could address the issue in one administrative action
  - Offers flexibility
  - Would be sensitive to wetland variation and adjacent water bodies with different criteria for different uses
  - Subcategories may be administratively easier to accomplish than the creation of a new use classification

- o No Change

  Significant Features
  - Leaves many important water quality related wetland functions unprotected
  - Makes application of WQS goals and objectives more difficult
  - Addressed by "natural waters" clause and antidegradation but without wetlands specific guidance
  - Maintains current administrative impediments to wetlands wastewater management

Consideration 2--

Parameters to Support Wetland Uses or Subcategories. If a new use classification or subcategory were adopted to incorporate important wetland functions and values in the water quality standards program, parameters to support that use would be required. Protective criteria could then be developed for the parameters identified.

The list of parameters ultimately selected and their protective criteria would depend on the wetland functions and values protected by the new classification or subcategory. The following parameters might apply to a use intended to maintain the water quality and ecological integrity of wetlands.

Physical	Biological	Chemical
o Water depth	o Composition	o pH
o Hydroperiod	o Diversity	o Metals/Toxics
o Suspended solids	o Productivity	o Dissolved oxygen
o Water temperature	o Pathogens	o Nutrients

The parameters selected should reflect the hydrologic variability of wetlands. Some wetland systems will have little or no standing water except during flood conditions. Other wetlands typically have standing or flowing water conditions. Parameters traditionally used as an indication of water quality and to measure assimilative capacity and impacts, such as dissolved oxygen, may be less appropriate for wetlands. Certainly this is true for wetlands that have little or no standing water most of the time. This characteristic of wetlands adds a level of uncertainty to selecting the appropriate parameters for protecting wetlands, since some of the parameters listed above have not previously been used to help define standards. For wetlands, more than water chemistry parameters are related to protecting wetland uses.

Some options which could be considered in addressing this issue follow.

o Use of physical parameters

Significant Features
- Some physical components may not have been applied in WQS previously (hydroperiod, water depth, etc.)
- May have implications beyond wetlands application (i.e., flow regulation)
- Are important to protect wetland functions and values
- Establishment of numeric criteria would be difficult for some parameters due to lack of relevant data
- Narrative criteria probably would be required for some parameters
- Compliance may be difficult to monitor due to lack of regulatory experience

o Use of biological parameters

Significant Features
- Biological parameters have been used to a limited degree by some states in their WQS
- Are important to protect wetland functions and values
- Would require biological monitoring
- Establishment of criteria may be difficult due to lack of relevant data
- Compliance may be difficult to monitor due to lack of regulatory experience

o Use of chemical parameters

Significant Features
- Now serves as the basis for WQS criteria
- Have specific application, but cannot protect wetland functions and values without other parameters
- Specific wetland needs not well defined
- Typical indicator parameters (e.g., dissolved oxygen) may not be applicable

o No Change

Significant Features

- Fails to recognize and protect significant wetland values and functions (e.g., aquatic productivity, erosion control, water quality enhancement, storm buffering, etc.)
- Maintains current administrative impediments to wetlands wastewater management

Consideration 3--

Types of Protective Criteria to Support Wetland Parameters. If a new wetland use classification or subcategory is adopted, parameters and criteria necessary to protect acknowledged uses must be identified. **Numeric criteria** have traditionally been preferred because acceptable loading rates, or effluent limitations, are derived more easily and violations can be more easily detected. For some of the parameters and conditions characteristic of wetlands, however, numeric criteria may not be so appropriate as **narrative criteria.** The uncertainty associated with establishing the "acceptable" levels of certain wetland parameters may be handled more appropriately by narrative criteria. Numeric criteria are probably more applicable to wetlands if site-specific standards are employed. Narrative criteria may be applicable on a generic scale if written to acknowledge the inherent variability in wetlands (i.e., base the standard on the ambient conditions in the wetland being evaluated).

The use of **seasonal criteria** may also be appropriate. Many wetlands, by nature, have wide variations in flow or water level throughout the year. Bottomland hardwoods, for example, may be dry year around except when storm events cause flood conditions. Water levels in cypress domes, which are hydrologically isolated from outside flows, vary with rainfall and groundwater levels. Many other important functions and values occur on a seasonal basis, such as waterfowl breeding, waterfowl habitat, vegetative reproduction, and organic and nutrient cycling. Therefore, hydroperiod and other parameters may require seasonal criteria; and for wastewater discharges, seasonal loading rates may be needed to protect wetland water quality and uses, and to meet antidegradation criteria.

Selecting the mechanisms for describing criteria is the last major consideration. Typically, minimum (or maximum) values, average values or a combination of both have been used to define protective criteria. For example, from the Florida Administrative Code (17-3):

> Dissolved oxygen--in predominantly fresh waters, the concentration shall not be less than 5 milligrams per liter. In

predominantly marine waters, the concentration shall not average less than 5 milligrams per liter in a 24-hour period and shall never be less than 4 milligrams per liter.

This approach may be feasible for numeric criteria describing water chemistry in well-defined wetlands systems. For narrative criteria, the use of "ranges of acceptable modifications" may be more appropriate.

The major options for developing protective criteria for wetland parameters are summarized below.

o Adopt numeric criteria

Significant Features
- Easier to relate to effluent limits
- Difficult to establish for parameters other than water chemistry
- Poor data base for some parameters in some systems
- May need specificity to wetland type
- Uncertainty exists about capability to protect wetlands functions and values

o Adopt narrative criteria

Significant Features
- Reflects wetland variability
- Accounts for unknowns and uncertainties
- More difficult to translate to effluent limits
- More dependent on the permit program for protecting wetland functions and values
- Uncertainty exists about capability to protect wetlands functions and values

o Adopt a combination of numeric and narrative criteria

Significant Features
- Provides greatest flexibility
- Can be easily tailored to specific wetlands
- Realistically may provide greater protection
- Poor data base on many wetlands systems may be limiting
- Uncertainty exists about capability to protect wetlands functions and values

o Adopt seasonal criteria

Significant Features
- Sensitive to wetland variability and seasonal cycles
- Complicates permit writing, monitoring and compliance

o Adopt minimum, maximum and/or average guidelines for numeric criteria

Significant Features
- Minimum criteria may have applicability for D.O.
- Average criteria may be useful for longer term effects
- Combined minimum/average criteria may have greater applicability and may be more sensitive to wetland variations
- Maximum criteria may be necessary to address acute effects
- Maximum criteria could be easily translated to effluent limits

o No change

Significant Features
- Fails to recognize and protect wetland functions and values (e.g., aquatic productivity, erosion control, water quality enhancement, storm buffering, etc.).

Consideration 4--

Establishment of Wetland Specific Standards. Through the existing WQS framework, standards can be established on either a generic or site-specific basis. Uses are always generic in that they apply on a state-wide basis. They may be designated, however, on a site-by-site basis as permitting or other administrative actions are required for a water body.

Criteria to support designated uses can be either generic or site-specific. Generic criteria apply to all water bodies with a given use classification within the state. For wetlands, the applicability of numeric generic criteria may be limited due to the variable characteristics of wetlands. Narrative modifiers are probably more appropriate for generic criteria. Site-specific criteria typically are applied only to individual sites where generic criteria are not appropriate. They are currently used for wetlands because existing standards do not adequately apply to wetlands in most cases.

The following features pertain to establishing wetland specific standards. Establishing standards and designating standards, while two separate actions, need to be considered together. In essence, a new water quality standard only takes on significance when particular water bodies are assigned a designated use. The subsequent section addresses those issues.

o Establish use or subcategory with generic narrative and/or numeric criteria

Significant Features
- Requires a WQS change
- Could be accomplished in a single administrative action

- Would be sensitive to wetland variability
- Would acknowledge differences between wetlands and free-flowing waters
- Development of site-specific effluent limits would be necessary and may be resource and time intensive for narrative criteria
- Would be difficult to develop numeric criteria on generic basis because of wetland variability
- Numeric criteria would be easier to translate to effluent limits.

o Establish use or subcategory and site-specific criteria where generic narrative or numeric criteria are not appropriate

Significant Features
- Requires a WQS change each time site-specific criteria are established
- Would be time and resources intensive
- Would be sensitive to wetland variability
- Easier to translate to effluent limits

o No change (invoke natural waters clause)

Significant Features
- Invoking a state's natural water clause does not require a WQS change
- Would be time and resource intensive
- Would be sensitive to wetland variability
- Easier to translate to effluent limits
- Discourages wetland discharges due to institutional obstacles

o No change (employ site-specific criteria)

Significant Features
- Employing site specific criteria requires a WQS change for each site-specific standards action
- Would be time and resource intensive
- Would be sensitive to wetland variability
- Easier to translate to effluent limits
- Discourages wetland discharges due to institutional obstacles

Consideration 5--

Application of Wetland-Specific Standards. If a wetland use classification or subcategory and its associated parameters and criteria are established, they can be applied in several different ways. How they are applied influences their effectiveness in meeting Clean Water Act objectives as well as administrative procedures.

A use classification or subcategory can be developed without designating all appropriate wetlands as such. In this situation, wetlands would be designated under the use classification only when an action or activity required it. In essence, although a use classification existed, it would be implemented on a site-specific, as-needed basis. Since each action would be a WQS change, public hearings and other administrative requirements would be necessary.

Another approach would be to designate all appropriate wetlands under the new use classification or subcategory upon its establishment. At that time, associated parameters and criteria also would be applied to the wetlands. This could reduce the need to have public hearings on each individual subsequent action, but it would do so effectively only if adequate technical information was available to classify wetlands on other than a site-specific basis.

Wetland use subcategories have been established in a few states, but they have been designated only on a site-specific basis due to the lack of data documenting the location and extent of various wetland types. As National Wetlands Inventory maps become available for more areas, this approach may change. The development of this technical information could improve administrative procedures significantly.

The existing "natural waters" clause included as part of a state's water quality standards regulation could be used to address wetland specific conditions without a water quality standards change. Administratively, this appears to be a straightforward approach. Potential constraints occur because it does not provide general guidance for assessing wetlands discharges to wetlands. Further, it does not incorporate the concept of extent of acceptable change reflected in established standards criteria.

o Designate wetland use classifications or subcategory on National Wetlands Inventory mapping or other wetlands Inventory system

Significant Features
- NWI mapping could provide technical basis for delineation
- NWI maps available for limited areas
- Resource requirements would be reduced with use of NWI maps
- Could be accomplished in one administrative action
- Would obviate the need for site-specific WQS changes
- Would emphasize differences between wetlands and free-flowing waters
- Could facilitate wetland permit decisions

- o Designate wetland use classification or subcategory on a site-specific basis

  Significant Features
  - Resource requirements related to delineating all wetlands could be reduced
  - Would shift significant responsibilities to the permit program
  - Limited experience available in permit staff related to wetland discharges
  - Higher degree of overview could be needed to assure protection of wetland functions and values
  - Would require a WQS change

- o Use existing "natural waters" clause

  Significant Features
  - Would use existing WQS and NPDES infrastructure
  - Would not require a WQS change
  - Would shift significant responsibilities to the permit program
  - Limited experience available in permit staff related to wetland discharges
  - Higher degree of overview could be needed to assure protection of wetland functions and values
  - Needs site-specific assessment
  - Would not incorporate the extent of acceptable changes as would a new classification or subcategory.

- o No change

  Significant Features
  - Requires a WQS change for each action
  - Is time and resource intensive
  - Requires a site-specific approach and fails to address the issue on program wide basis
  - Maintains current administrative impediments to wetlands wastewater management.

3.3 NPDES PERMIT PROGRAM

3.3.1 NPDES Purpose and Background

The NPDES Permit Program requires a permit for the discharge of pollutants from any point source into waters of the United States. The program is authorized under Section 402 of the Clean Water Act (PL 92-500 as amended). The provisions of the Clean Water Act mandate that administration of the NPDES Permit Program be delegated to those states whose program has been approved by EPA. All states within Region IV with the exception of Florida have been delegated primary responsibility for administering the NPDES Permit Program. Although the EPA may require certain NPDES permit conditions, the states are not precluded from adopting more stringent permit conditions.

An NPDES permit should include at a minimum: (1) effluent limits (maximum daily loadings or concentrations in treated effluent), (2) a schedule for complying with the effluent limits, (3) monitoring and reporting requirements for which the discharger is responsible and (4) sludge disposal requirements.

Figure 3-3, outlining the NPDES process, was developed based on EPA experience with assisting permit applicants in complying with NPDES Permit regulations. Permits may be issued to Publicly Owned Treatment Works (POTWs) for any length of time up to five years. Water quality standards and subsequent effluent limits on which permit conditions are based are reviewed every three years. If effluent limits or water quality standards are modified after a permit is issued, subsequent alterations to permit requirements also may be made.

The general framework for the NPDES permitting process is organized into four major sections: permit application, effluent limitations, implementation and special permit conditions. Figure 3-3 illustrates how these sections are coordinated in the overall NPDES permitting process. Figure 3-4 outlines the general procedures followed to establish effluent limitations. Each of the four major sections is described below.

Permit Application. The permit application process, Activities 1-4 on Figure 3-3, requires identification of all pollutants that may be present within a wastewater stream and those that must comply with water quality standards. Hence, a proposed discharger must know the constituents of the wastewater and their importance. Average and maximum quantities of wastewater to be discharged also must be established, and the frequency and volume of discharge must be provided. Permit applicants are required to provide different levels of detail depending upon individual state requirements as well as size, location and type of discharge. Permit applications do not cur-

Figure 3-3. Overview of the NPDES Permit Program

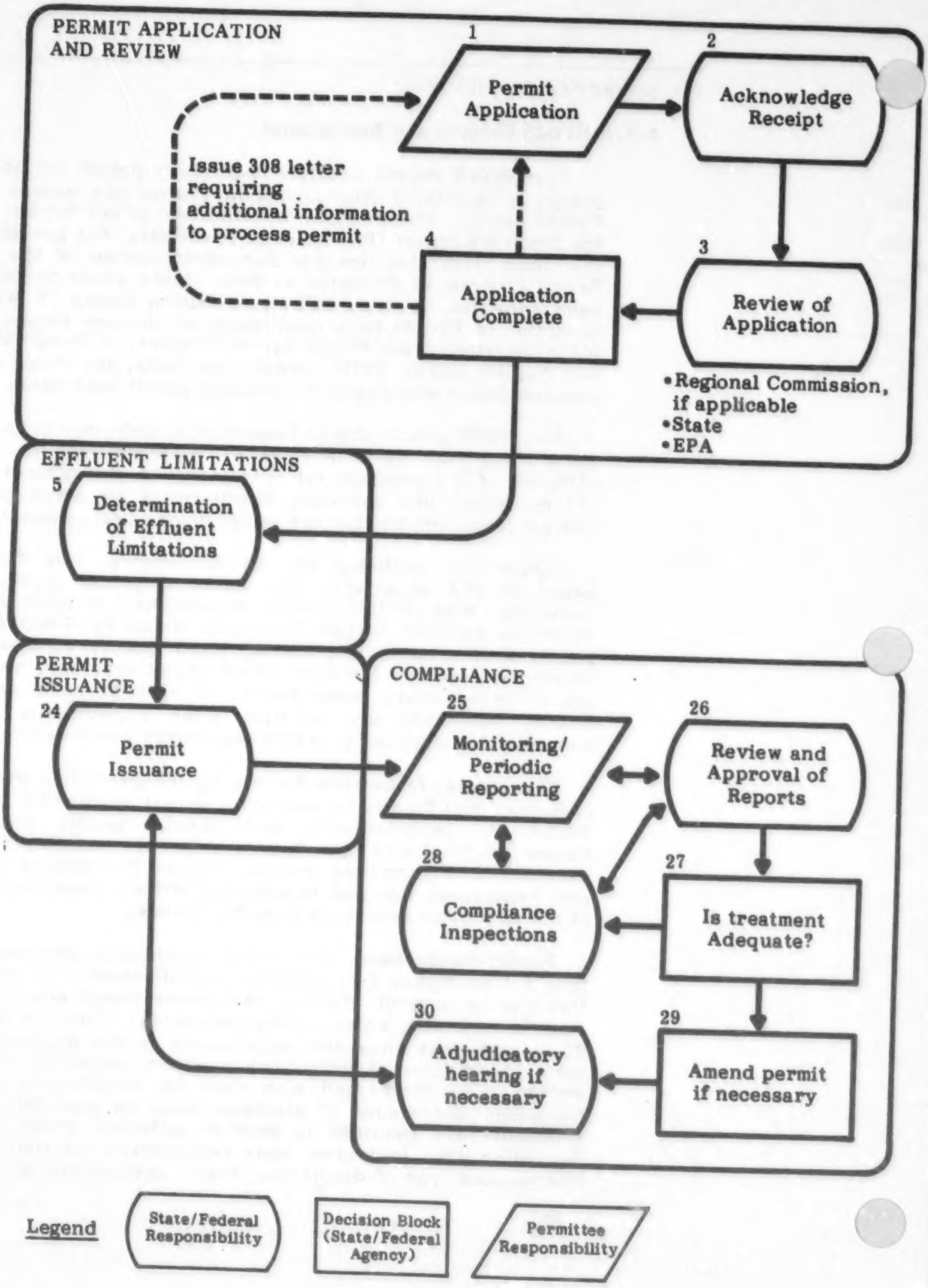
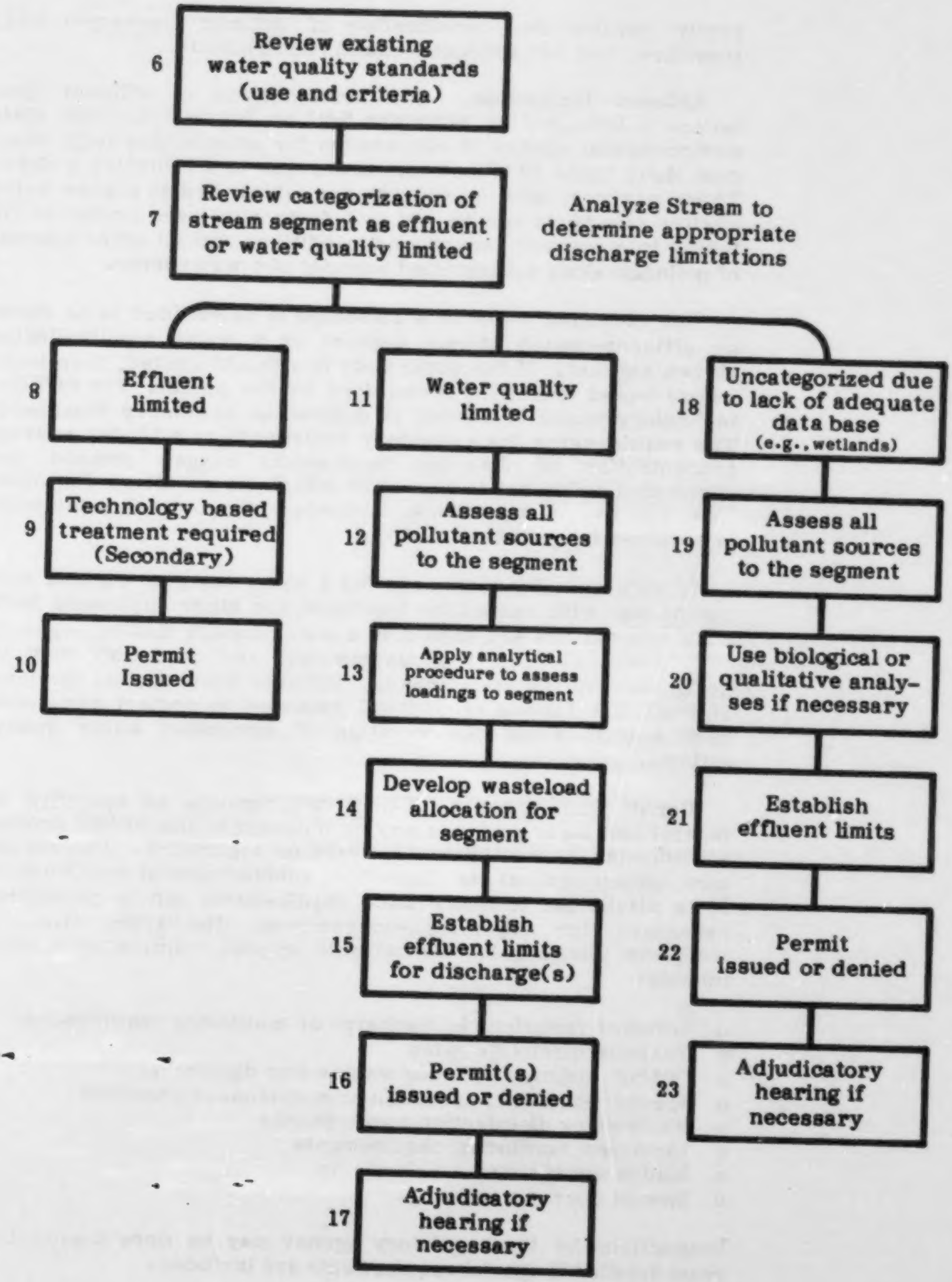

PERMIT APPLICATION AND REVIEW
1
Permit Application
2
Acknowledge Receipt
Issue 308 letter requiring additional information to process permit
4
Application Complete
3
Review of Application
•Regional Commission, if applicable
•State
•EPA
EFFLUENT LIMITATIONS
5
Determination of Effluent Limitations
PERMIT ISSUANCE
24
Permit Issuance
COMPLIANCE
25
Monitoring/ Periodic Reporting
26
Review and Approval of Reports
28
Compliance Inspections
27
Is treatment Adequate?
30
Adjudicatory hearing if necessary
29
Amend permit if necessary
Legend
State/Federal Responsibility
Decision Block (State/Federal Agency)
Permittee Responsibility

Figure 3-4. Determination of Effluent Limitations


6
Review existing water quality standards (use and criteria)
7
Review categorization of stream segment as effluent or water quality limited
Analyze Stream to determine appropriate discharge limitations
8
Effluent limited
11
Water quality limited
18
Uncategorized due to lack of adequate data base (e.g., wetlands)
9
Technology based treatment required (Secondary)
12
Assess all pollutant sources to the segment
19
Assess all pollutant sources to the segment
10
Permit Issued
13
Apply analytical procedure to assess loadings to segment
20
Use biological or qualitative analyses if necessary
14
Develop wasteload allocation for segment
21
Establish effluent limits
15
Establish effluent limits for discharge(s)
22
Permit issued or denied
16
Permit(s) issued or denied
23
Adjudicatory hearing if necessary
17
Adjudicatory hearing if necessary

rently require the identification of wetland discharges and, therefore, may not address wetland requirements.

Effluent Limitations. The determination of effluent limitations is indicated by Activities 5-23 on Figure 3-4. Each state environmental agency is responsible for establishing total maximum daily loads (TMDLs) for discharges to all surface waters. These maximum daily wasteloads are established to assure water quality standards can be met and designated uses protected by taking into account background conditions and all other sources of pollution along a designated segment of a water body.

The receiving water of a discharge is determined to be either an effluent-limited stream segment or a water quality-limited stream segment. If the water body is effluent-limited, then technology-based treatment is required by the permit. For POTWs, technology-based treatment is defined as secondary treatment. The requirements for secondary treatment are a 30-day average concentration of five-day biochemical oxygen demand and suspended solids not to exceed 30 milligrams per liter. For other than POTWs, best available technology economically achievable is required for pollutant control.

If water quality standards for a water body or wetland cannot be met with secondary treatment (or other applicable technology-based limits), then it is a water quality-limited segment; more stringent control of wastewaters and/or runoff must be designated by the state agency. Effluent limits dictate the level of treatment (above secondary) required to protect designated uses and to avoid the violation of associated water quality criteria.

Permit Requirements. Other requirements as specified by federal and state guidance may be included in the NPDES process as indicated by Activities 24, 29-30 on Figure 3-3. The regulatory agency can, at its discretion, include special requirements for a discharger to meet. Such requirements can be considered necessary for other-than-conventional discharges (i.e., a wetlands discharge). Conceivable special requirements could include:

- Seasonal variations in discharge or monitoring requirements
- Maximum discharge rates
- Outfall design to enhance wastewater dispersion
- Special treatment, operation or maintenance practices
- Wastewater disinfection requirements
- In-stream monitoring requirements
- Sludge management requirements
- Special operator training.

Inspections by the regulatory agency may be more frequent or more detailed if special requirements are included.

Compliance/Monitoring. The discharger must inform the agency controlling permitting procedures of the schedule for commencing a discharge and any other aspects of implementation that may affect the quality of the receiving waters. Design plans for the location and type of outfall, construction procedures, and start-up and monitoring activities should be established in conjunction with the regulatory agency prior to implementation of a wetlands discharge. The discharger is responsible for most compliance and monitoring requirements, Activities 25-28 on Figure 3-3. The regulatory agency periodically will inspect discharge facilities to determine whether implementation procedures are properly conducted. Monitoring reports are submitted to the agency by the discharger to attest that permit requirements for discharge loadings are being met.

3.3.2 NPDES Program Requirements and Current Practices

The NPDES program is tied closely to the WQS program since the latter establishes the uses and criteria for protecting a water body. Effluent limitations are established through the NPDES permitting process to assure wastewater dischargers will not degrade designated uses nor violate standards criteria.

Effluent limits often are based on mathematical equations that predict responses of a water body to wastewater discharges and runoff. Most of the available models for predicting these responses, however, are variations of dissolved oxygen models originally developed for free-flowing streams. While Region IV states rely on these models to some extent, most acknowledge the shortcomings of the models when applied to wetland systems. If analytical models cannot be modified to provide acceptable reliability, then on-site biological, chemical and physical assessments are conducted, and effluent limitations are based on best professional judgement. Biological assessments are receiving increased use in setting effluent limitations for wetland discharges. The states and EPA, however, are concerned about "a reasonable scientific basis" and assurances of "reproducible, confident and defensible" water quality decisions.

All states in Region IV with the exception of Florida have the delegated authority to administer their own NPDES Program. The overview role EPA maintains for the delegated states results in the review of a selected 10 percent of major discharges of the state NPDES permits. For non-delegated states, EPA issues a draft permit for states to review and certify before final permits are issued. Although some procedural differences exist for issuing permits and adopting permit reuqirements in each Region IV state, the greatest difference is in the approach used for determining effluent limits for discharges to wetland areas. At present, a formal agreement exists between the states and EPA Region IV on how wastewater permit limitations are to be established. Both EPA and the states have defined responsibilities for the development of appropriate effluent limitations. Under Section 303(d) of the Clean Water Act, the states are charged with developing allowable wasteloads that will insure the attainment of water quality standards. This section of the Act also requires EPA to approve or disapprove these wasteloads within 30 days of submission. Although a general agreement exists between the states and EPA Region IV, differences occur in the method of establishing effluent limits for wetlands.

Table 3-4 summarizes the current practices of state agencies in implementing the NPDES program for wetlands discharges. Some procedures or requirements are applied to wetlands discharges that are not applied to more conventional discharges to free-flowing streams.

3.3.3 NPDES Wetland Discharge Considerations

The WQS and NPDES programs are linked closely. Effluent limitations, which are necessary to obtain a wastewater discharge permit, are based on defined water quality standards (uses and associated criteria). In essence, the requirements of both programs must be met before a discharge can be permitted.

The Construction Grants program has been an integral part of the NPDES process by providing guidelines for planning, design and construction. With the decreasing role of this program, particularly for smaller communities, the NPDES programs could incorporate some of the Construction Grants guidelines pertaining to water quality and performance criteria.

Several wetland discharge considerations are presented that may help achieve the purpose of the NPDES permitting programs for wetlands discharges (Activity numbers refer to activities outlined in Figure 3-3 and 3-4):

1. **Additional permit information**

2. **Potential effluent limitations parameters**

3. **Techniques for determining effluent limitations for a wetlands discharge**

4. **Wetland specific permit requirements/conditions**

5. **Permit compliance for wetlands discharges.**

Most of the issues raised relate primarily to the permit application process, and permit conditions and the determination of effluetn limits. These issues will be evaluated in the following section.

Table 3-4. Summary of Current State Practices Associated with the NPDES Program.

State	Use of special permit conditions for wetlands discharge?	Application of site-specific effluent limits for wetland? Activity 6	Application of "parent" stream segment effluent limits? Activity 7	Use of models to determine effluent limits? Activity 13	Use of biological assess. to determing effluent limits? Activity 20	Use of special wetlands monitoring? Activity 25
Alabama	-	-	-	X	-	-
Florida	X	-	X	X	X	X
Georgia	-	-	X	X	X	-
Kentucky	-	-	-	-	X	-
Mississippi	-	-	-	-	X	X
North Carolina	-	X	-	-	X	X
South Carolina	-	X	-	-	X	X
Tennessee	-	-	-	X	X	-

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[1] Refers to Figure 3-3 or 3-4.

3.3.4 Alternatives for NPDES Wetland Discharge Considerations

In the implementation of the NPDES permitting program, a wetlands discharge basically is considered the same as any other discharge. Due to the many important functional differences between wetlands and continuous, free-flowing aquatic systems, some modifications to the program should be considered. Potential alternatives for incorporating wetlands-specific adaptations to the NPDES program are discussed below.

From a practical viewpoint, it probably is not necessary for every potential wetlands discharger to provide the same amount of information. If the wetland being considered has not been classified unique or endangered, and loading rates are conservatively low based on existing information, less information may be needed for permit decisions than if the wetland area is unique or endangered, considered sensitive to modifications or would receive a relatively high loading rate. The technical aspects of this "tiered" approach are discussed further in section 4.4, 5.4 and 7.4. Section 5.4 pertains specifically to the technical aspects of administering the NPDES program. Sections 4.4 and 7.4 describe technical requirements for decision making.

One approach to "tiering" information requests for wetlands discharges is based on two primary determinants: wetland type and hydraulic loading (incorporating wastewater flow and wetland size). For purposes of classifying wetland type relative to wastewater discharges, three distinctions are proposed:

Type 1:
Altered; encroached upon by development; or widespread in distribution.

Type 2:
Pristine; endangered; or sensitive to hydrologic or water chemistry changes.

Type 3
Unique; or classified as a critical habitat

Type 1 wetlands typically should be given first consideration for a wetlands discharge. Often wastewater discharges can be used to restore altered wetlands if the hydrologic regime of a natural wetland has been altered significantly. Discharges also could serve to maintain or preserve wetlands being surrounded or stressed by nearby development. While these enhancement features may not be common to all Type 1 wetlands, they should be considered whenever possible. Wetlands that have widespread distribution and that are not highly sensitive to hydrologic or water chemistry modifications also would be included in this wetland type.

Type 2 wetlands are those: 1) in their natural state with few, if any, impacts from development, 2) endangered in extent or 3) are especially sensitive to hydrologic or water chemistry changes. The use of these wetlands for a wastewater discharge should be avoided if possible. An endangered wetland type is one that has been subjected to development or has otherwise been reduced in extent.

Type 3 wetlands are those that are unique or classified as a critical habitat. Unique wetlands are those extremely limited in extent. A wetland commonly found in one state or region of the country may be unique to another state or region. Some wetlands are considered to be critical habitat for protected species, migratory waterfowl and other wildlife. Modifications of such wetlands could have widespread ecological impacts. As a result of the value of these wetlands, their use for wastewater management is discouraged, along with all other developmental activities that could threaten their condition.

The second determinant in differentiating wetland information requests for dischargers is hydraulic loading--combining wastewater flows with wetland size. Two hydraulic loading levels are suggested.

Level 1:

Less than or equal to 1.0 inch per week with flows from single pipe discharges less than or equal to 0.250 mgd (33,425 ft^3/day).

Level 2:

Less than or equal to 1.0 inch per week with flows from single pipe discharges greater than 0.250 mgd, or

Greater than 1.0 inch per week.

The rationale for establishing two levels, and their distinction, should be understood. The tiered approach primarily is intended to acknowledge within the decision making framework the differences between those potential discharges with a relatively low degree of uncertainty and risk, and those with a higher degree of uncertainty and risk. The establishment of tiers, and their differences, can be based only on the best information available. This is done with the understanding that as the data base expands, modifications in the approach might be necessary. The benefits of establishing such an approach within the decision making framework must be balanced against the associated uncertainty.

A hydraulic loading rate standard of 1.0 inch/week was selected as a conservative rate for most wetland systems in the southeastern United States based on information from existing wetlands discharges. The maximum flow rate for single pipe discharges was included to limit this level to relatively small discharges. The value of 0.250 mgd was selected as representative of small discharges. The flow ceiling also is included because hydraulic loading alone does not describe fully impacts to a wetland. When wastewater is discharged to a wetland, it does not fully mix with the entire water body. An expanding zone of influence develops around the discharge point. Without a flow ceiling, a relatively large discharge could have a small hydraulic loading if the wetland is also large; yet only a relatively limited area near and downgradient from the discharge is likely to be impacted. The use and determination of the "effective" wetland area is described in subsequent chapters. The flow ceiling would not apply to wetland discharges that incorporate distribution systems such as multi-point diffusers, overland flow, etc., since these systems encourage better and more uniform distribution of wastewater throughout the wetland. Therefore, if hydraulic loadings or flow rates exceed 1.0 inch per week or single pipe discharges exceed 0.250 mgd, respectively, the discharge is classified as Level 2. This means that the discharger should provide more information than for a Level 1 discharger. The permit writer should have flexibility to request information commensurate with the extent the hydraulic loading or flow exceeds the suggested values, or when more valuable wetland types are used.

The proposed method of tiering is summarized by Table 3-5. A Level 1 discharge to a Type 1 wetland represents the conservative discharge conditions fundamental to the suggested tiering approach. The relative degree of acceptability of discharge levels and wetland types is indicated. The tiered approach affects the permit information requested, the establishment of effluent limits and the post-discharge monitoring requirements.

Table 3-5. Tiering Approach for Information Requests.

	Level 1	Level 2
Hydraulic Loading and Flows	Loading ≤ 1"/wk with Q ≤ 0.250 mgd for single pipe discharges	Loading ≤ 1"/wk with Q > 0.250 mgd for single pipe discharges or Loading > 1"/wk
Type 1 Altered or widespread wetland	- Tier 1 - Preferred, with minimum information requirements	- Tier 2 - Mostly acceptable, with some additional information required
Type 2 Pristine, Endangered or Sensitive Wetland	- Tier 2 - Acceptable in some circumstances with additional information required	- Tier 2 - Discouraged
Type 3 Unique or Critical Habitat Wetland	- Tier 2 - Discouraged	- Tier 2 - Not Recommended

This tiering scheme is based on the approach that the primary wastewater management objective of a Tier 1 discharge is disposal/assimilation. If nutrient removal or some level of renovation is expected in the wetland, more detailed analyses will be necessary than those proposed for a Tier 1 discharge in later chapters. More information would be required for a permit application and for assessing the assimilative capacity of the wetland and downstream impacts. Tier 1 represents the minimum information requirements associated with wetland discharges. Tier 2 represents an additional level of risk or uncertainty for which additional information is warranted. The exact nature of Tier 2 information requests would be determined by the state/federal regulatory agency.

Another method for handling this situation would be to establish 0.5 inch per week as the preferred hydraulic loading rate for those discharges desiring enhanced nutrient removal in the wetland. Some studies (Nichols 1983) indicate this hydraulic loading rate would facilitate greater than 50 percent nutrient removal.

This tiering approach also assumes that effluent limitations or performance criteria are met. The suggested analyses for post-discharge monitoring (Section 7.5) are based on this assumption. If the expected conditions are not met in the wetland or downstream waters, additional analyses may be necessary to identify the source of the problem.

Additional Permit Information. Since every discharge to wetlands considered to be waters of the U.S. will require a NPDES permit, the required permit information may be the best mechanism for characterizing wetlands discharges. Several options are available to responsible agencies which might optimize the process for permitting wetlands discharges and assure their compliance.

The first alternative is obtaining supplemental information to the existing permit application through the permit review process. The NPDES application form for municipal wastewater discharges has two formats. Short Form A is to be used for discharges less than 1 million gallons per day (mgd). Standard Form A - Municipal is to be used for discharges greater than 1 mgd. While the standard form requires more information than the short form, neither requires sufficient information for examining wetlands discharges. With the existing format, however, additional information can be required of a discharger on the standard form. This may be the easiest means of obtaining wetlands-specific information.

The standard form is divided into four sections: Applicant and Facility Description, Basic Discharge Description, Scheduled Improvements and Schedules of Implementation and Industrial Waste Contribution to Municipal System. Since this better approaches the level of detail needed to adequately assess a wetlands discharge, applicants should be encouraged to use this form regardless of size. The following information could be requested in the appropriate sections of the application form.

NPDES STANDARD FORM A - WETLAND OPTIONS

1. Applicant and Facility Description
   - USGS map showing treatment facility and discharge point(s)
   - Wetland type
   - Wetland size
   - Wetland ownership and availability

- Wetland access
- Wetland environmental sensitivity and uniqueness (obtained from state or federal agencies)

2. Basic Discharge Description
   - Type of discharge structure
   - Predominant vegetation type
   - Seasonal wastewater flow characteristics (in conjunction with hydroperiod)
   - Ambient water quality conditions in wetland
   - Protected species habitat or presence
   - Hydroperiod (normal period of inundation) (Tier 2)
   - Current wetland uses (WOS program) (Tier 2)
   - Inflows to and outflows from wetland (Tier 2)
   - Soil types within wetland (Tier 2)

3. Scheduled Improvements and Schedules of Implementation
   - Wetland specific construction considerations, e.g., use of boardwalks, minimizing soil compaction, runoff/erosion control, scour control, minimizing vegetation disturbances
   - Method of mitigating construction impacts
   - Relationship of construction activities to seasonal variability in wetland (particularly hydroperiod, reproductive cycles of vegetation, wildlife and waterfowl) (Tier 2)

4. Industrial Waste Contribution to Municipal System
   - Acute toxicity potential to wetlands or wildlife
   - Chronic toxicity potential to wetlands vegetation or wildlife (Tier 2)

These wetlands-specific information requests suggested are in addition to the standard information required. They also could be requested as part of a 308 letter (request by the permitting agency for more information) designed specifically for a wetlands discharge. The map showing the facility location and proximity to wetlands, in conjunction with established parameters (e.g., presence of channels, distance of discharge from wetland), also could provide a more definitive basis for identifying wetlands discharges. This could be important to administering the requirements applied specifically to wetlands discharges.

The following options are available for addressing the issue of wetlands-specific permit information.

o Use the Standard Form A NPDES permit application for any potential wetlands discharge, regardless of size

Significant Features
- Requires regulatory change
- Would provide early, implementable mechanism for obtaining additional wetlands information

- Would allow for the identification of wetland discharges

- Modify all NPDES permit application forms to include a map displaying proposed discharge location

  Significant Features
  - May be more difficult to implement due to federal Office of Management and Budget requirements
  - Would standardize wetland discharge information requests
  - Would facilitate the application review process for all discharges
  - Would allow for the identification of wetland discharges

- Modify all NPDES permit application forms to include wetlands discharge information

  Significant Features
  - May be more difficult to implement due to federal Office of Management and Budget requirements
  - Would standardize wetland discharge information requests
  - Would facilitate the application review process for all discharges
  - Specifying appropriate information for all applicants could be difficult

- Modify existing review procedures to require additional wetland discharge information

  Significant Features
  - Requires procedural change
  - Could be accomplished through a standardized 308 letter
  - May not be applied consistently unless guidelines defined wetlands discharge
  - Cannot now identify wetland dischargers

- Establish tiered approach for obtaining information based on loading rate and wetland type

  Significant Features
  - Requires development of tiers
  - Requires procedural change
  - Uncertainty of tiering levels based on limited data base for some wetlands
  - Allows for level of information requested to be dependent upon loading rates, wetland type, etc.
  - Difficult to identify when a wetland discharge is proposed and when to require additional information

- No change

  Significant Features
  - Fails to allow the identification of wetlands dischargers

- Fails to provide sufficient information to write permits to protect wetland functions and values

Consideration 2--

Potential Effluent Limitation Parameters. Several parameters typically not addressed by water quality standards are important to the functions and values of wetlands. The most important of these is hydroperiod, the cycle of natural hydrologic fluctuations. Many wetland processes and characteristics are based on its hydroperiod. Although hydroperiod is not a conventional water quality parameter, its relationship to water quality and the condition of the wetland itself is well documented. A list of wetland functions and values not addressed by current use classifications was presented in Section 3.2. If these uses ultimately are to be protected under the WQS program, criteria need to be established for and permits need to protect these wetlands functions and values. In essence, a physical parameter such as hydroperiod or water depth may be as necessary to assure protection of wetlands uses as chemical parameters such as BOD and dissolved oxygen.

Effluent limitations must be established for the parameters addressed by water quality standards criteria. The list of effluent-limitation parameters ultimately will be related to water quality standards adopted for wetlands. Likely parameters could include flow (including seasonal variations) to maintain hydroperiod, pH, suspended solids, BOD, nutrients, heavy metals, and fecal coliforms. Nutrient and heavy metal assimilation occur in wetlands but cannot be assumed to be total sinks. If biological diversity must be maintained for wetland water quality standards, effluent limits should be established for parameters affecting biological diversity (e.g., flow, nutrients, toxics). Additionally, effluent limitations or performance criteria could be delineated to meet downstream standards as well.

The question has been raised concerning the mechanism for setting limits for a non-water chemistry parameter such as hydroperiod. The mechanism would be the same as for any other parameters; that is, establishing ambient conditions and then prescribing the amount of variability from those conditions that is acceptable. As a result, understanding cause and effect in a wetland is important. For example, a narrative criterion may be established to maintain biological diversity. But how is this addressed by effluent limits? It is essential that the causes of change in biological diversity be understood; then, effluent limits can be established for these parameters. Due to the importance of hydraulic loading to wetland maintenance and water quality, wastewater flows into wetlands should be controlled by effluent limits in most cases. The following actions could be taken to address this issue.

- o Adopt wetlands-specific guidelines for use of physical parameters (e.g., velocity, hydraulic loading rates, etc.)

  Significant Features
  - WQS criteria do not typically address physical parameters, WQS change may be needed
  - Would be more protective of wetland uses
  - Guidance is needed to assist permit writers
  - Although important to protect wetland values and functions, the basis for physical parameters may not be well known

- o Adopt wetlands-specific guidelines for using chemical parameters (e.g., DO, nutrients, pH)

  Significant Features
  - Now serves as basis for effluent limits
  - Easily related to WQS
  - Use of chemical parameters alone may not be sufficient to protect wetland functions and values
  - Basis for chemical parameters for all wetland types may not be well known

- o Use combination of physical, biological and chemical parameters

  Significant Features
  - Would best protect or maintain wetland uses
  - Guidance is needed for some parameters
  - The basis for using some parameters may not be well documented

- o No change

  Significant Features
  - Water chemistry parameters and fecal coliform alone do not protect some important wetland functions and values

Consideration 3--

Techniques for Determining Effluent Limitations for a Wetlands Discharge. When a wastewater discharge permit application is received, the permit writer evaluates existing wasteload allocations as a preliminary assessment of effluent limits. If wasteload allocations do not exist, the water quality standards must be reviewed and a site-assessment conducted to establish effluent limits. Currently, this is required of most wetland discharges. As a result, effluent- and water quality-limited designations have less applicability to wetlands. This explains the third category displayed in Figure 3-4: those water bodies that essentially are unclassified.

Wetlands discharges, however, also should be understood in context of effluent- and water quality-limited designations since these terms typically are used. If a wetland is designated as effluent-limited, the establishment of effluent limitations is simplified, since effluent-limited segments require technology-based effluent limitations. Technology-based effluent limitations are defined and set by regulations (40 CFR part 133 September 20, 1984). Effluent quality varies for different types of facilities (e.g., 30 mg/l for both biochemical oxygen demand (BOD) and suspended solids (SS) are required for activated sludge facilities, while 45/45 is required for trickling filter facilities). Nutrients sometimes are included on a site-specific basis.

If the wetland is classified as water-quality limited, it can be more difficult to establish effluent limitations. Modeling or on-site assessments may be necessary to define effluent limitations. These methods have some limitations for wetlands discharges, including how to establish effluent limitations from qualitative analyses. Chapter 5 addresses the technical aspects of determining whether a wetland is effluent- or water quality-limited and options for defining effluent limitations in wetlands classified other than effluent-limited.

The essential aspect of establishing effluent limits is meeting standards in the receiving water and downstream waters. Related to this, should a wetland have the same designation as its adjoining stream segment? Often this is the method used for establishing effluent limits in wetlands. But under some conditions this designation might not be accurate. Site-specific assessments will help resolve the potential discrepencies of this method.

Another reason the effluent- and water quality-limited designations have restricted application to wetlands is the need to have effluent limits for parameters other than the water chemistry constituents affected by treatment. In wetlands, the scheduling and rate of flow can be essential to assimilation and protection of the wetland. The effluent- and water quality-limited designations do not address these physical parameters.

Despite the problems encountered, effluent limitations still must be developed. Region IV states have two basic methods for establishing effluent limitations for a wetlands segment classified other than effluent-limited: modeling and on-site assessments. They often are used together for wetlands. Both have deficiencies for adequately defining effluent limitations to a wetland.

Mathematical models typically are constraining because they were not developed for use with wetlands systems, where channels are poorly defined and low-depth sheet flow of water is common. Most models used to define effluent limitations in free-flowing watercourses are based on Streeter-Phelps dissolved oxygen models, which predict the dissolved oxygen reduction based on factors such as organic loading (BOD), water temperature and velocity. Many versions of dissolved oxygen models are available, but most are not adequate for application to systems with the hydraulic characteristics common to most wetlands. With some adaptation these models might be more useful, but constraints still would exist because wetland flows usually are not confined to channels, have sluggish flow characteristics (including intermittent flows) and have extensive interactions with vegetation, which affects reaeration and the removal of organic matter.

More sophisticated models have been developed that could assess wetland discharges and define effluent limitations more clearly. These models, however, require an extensive data base and are more difficult to apply. Further, such models would have to be adapted to specific wetlands systems.

Some problems also have been encountered with on-site assessments. Specific guidelines have not been developed, so such assessments often are incomplete or not reproducible. To assess the level of treatment required beyond secondary, water quality or vegetative analyses often are required. Typically, water chemistry characteristics include dissolved oxygen, BOD, pH and suspended solids. Nutrient analyses might be required. However, if the wetland is connected to downstream systems, the effects of discharges on downstream uses also would be necessary. Water and nutrient budgets may be necessary in some situations. In addition to a vegetation analyses, the onsite survey in support of determining effluent limits for wetlands should include an assessment of other pollutant sources, watershed modifications, hydrologic interconnections, and current and future wetland uses. Due to the seasonal variability in the water quality characteristics of wetlands, seasonal influences should be addressed by any method of establishing effluent limitations. Options for establishing effluent limits for wetlands discharges include the following:

o Classify all wetlands as effluent-limited, requiring only secondary treatment, unless other major discharges exist

Significant Features
- Method currently most used
- Simplifies determination of effluent limits
- May need to include other parameters, such as loading rates and seasonal limits
- May not protect certain sensitive wetland types
- May not be responsive to WQS requirements

- Use a tiered approach of establishing effluent limits based on loading rates

  Significant Features
  - Simplifies determination of effluent limits
  - May not protect certain sensitive wetland types
  - Requires development of tiers
  - Uncertainty of tiering levels based on limited data base
  - May be insensitive to other parameters and wetland responses

- Adapt currently used models or use more sophisticated models to establish effluent limits for wetland discharges

  Significant Features
  - Can be labor or data base intensive
  - Model calibration and verification could be difficult or expensive
  - Could improve assessment of wetlands discharges
  - May not be applicable to all systems
  - Requires site-specific analysis to develop data base specific to each discharge
  - Requires an experienced modeler
  - May require development of model algorithms

- Develop a standard method for performing qualitative analyses

  Significant Features
  - Would improve consistency
  - Would require adoption of guidelines
  - Would improve reproducibility of current methods
  - May be difficult to translate to effluent limits
  - Requires site-specific analysis to develop data base to be used in establishing effluent limits

- No change

  Significant Features
  - Does not address need for reproducible and protective methods
  - Uncertainties in establishing effluent limitations would remain

Consideration 4--

Permit Requirements and Conditions. The permitting process is the primary mechanism for assuring water quality standards are met in waters receiving wastewater and in protecting downstream and groundwater water quality. It is also the means for meeting antidegradation requirements. Downstream impacts are an important aspect of antidegradation. Effluent limits are the primary permitting mechanism for assuring maintenance of water quality criteria. For wetlands, however, additional permit requirements and conditions may be equally important to meeting standards criteria and antidegradation requirements and assuring that downstream uses are maintained and protected.

Additional permit requirements that could be considered for wetlands discharges include:

1. Prescribed pretreatment, particularly if a portion of the wastewater emanates from industrial sources
2. Seasonal operation variability
3. Implementation schedule for construction, discharging, and operation and maintenance
4. Specific details for monitoring requirements and reporting
5. Ownership or access requirements
6. Back-up discharge alternatives
7. Performance criteria - instream water quality levels which should be met in downstream waters.

The actual permit requirements or conditions placed on a wetland's discharges would relate to the information requested on the permit application. This again introduces a tiered approach to implementing permit conditions. For example, permit conditions probably would be more extensive for a wetland receiving a relatively large hydraulic load than for one receiving a conservative load. Likewise, more requirements would be placed on a discharge to a pristine wetland than to a wetland which had been previously degraded. This might also serve to encourage "restorative" discharges. Monitoring requirements, discussed in Section 7.4, also could be established using a tiered approach based on flow, hydraulic loading and wetland type.

The Water Quality Standards Program defines protective criteria. **Performance criteria** established through the permitting process augment effluent limits established to meet standards criteria. Instream performance criteria may be related to parameters not addressed specifically by the standards criteria, but which are essential to protecting identified uses and associated water quality. Performance criteria are related specifically to the levels of wastewater loading and expected assimilation and, therefore, provide an additional means of assessing instream water quality and wastewater impacts. Performance criteria could be established and enforced to assure that downstream standards are met. They are based on a calculated level of assimilation in the receiving water or wetland.

Potential options for wetlands permit requirements and conditions include the following:

- **Use of prescribed levels of pretreatment**

  Significant Features
  - Reduces levels of industrial components (metals, salts, toxics) in wastewater discharges

- **Use of seasonal operational requirements**

  Signficant Features
  - Would be sensitive to wetland needs and variability
  - Acknowledges additional requirements may be appropriate for wetland discharges to ensure protection of wetland functions and values
  - Provides flexibility for different wetland systems

- **Use of implementation schedule**

  Significant Features
  - Would be responsive to natural wetland cycles
  - Would be sensitive to wetland needs and variability
  - Acknowledges additional requirements may be appropriate for wetland discharges to ensure protection of wetland functions and values

- **Use of monitoring and reporting requirements**

  Significant Features
  - Improves the ability to regulate wetlands discharges
  - Requires development of relevant monitoring program components
  - Enhances ability to mitigate detrimental wetland impacts
  - Would increase knowledge base concerning wetland responses to wastewater discharges
  - Monitoring programs need to be related to specific reporting requirements to assist compliance reviews
  - Acknowledges additional requirements may be appropriate for wetlands discharges to ensure protection of wetland functions and values
  - Level of detail required could be tiered, based on loadings

- **Use of ownership or access requirements**

  Significant Features
  - Would ensure uninterrupted use of wetland - Improves ability to regulate wetland discharges - Enhances ability to mitigate detrimental wetland impacts
  - Acknowledges additional requirements may be appropriate for wetland discharges to ensure protection of wetland functions and values
  - May discourage wetlands use in some cases if CG funding is unavailable for wetlands purchase

- o Use of in-stream performance criteria

  Significant Features
  - Improves ability to regulate wetlands discharges
  - Requires development of relevant in-stream or downstream performance criteria
  - Enhances ability to mitigate detrimental wetland impacts
  - Would increase knowledge base concerning wetland responses to wastewater discharges
  - Acknowledges additional requirements may be appropriate for wetland discharges to ensure protection of wetland functions and values
  - performance criteria need to be specific and related to reporting requirements to assist compliance review

- o No change

  Significant Features
  - Fails to provide guidance or consistency
  - May not be sufficient to protect wetland functions and values
  - May lead to vaguely written permits which may limit compliance reviews

Consideration 5--

Permit Compliance. Permit compliance is related specifically to the effluent limits and conditions of the permit and the way it is written. A vaguely written or non-specific permit provides little basis for compliance review. A specific permit, with well-defined permit conditions or performance criteria, provides a solid foundation for compliance review.

The compliance process also might be improved by increasing the scope or frequency of review. Compliance inspections could be conducted more frequently, at least during the construction/-installation phase and first year of operation, to assess the overall operation of the facility and wetlands discharge impacts. Mitigation of construction/installation impacts can be critical in wetlands.

For permit compliance review to be effective, the permit writer should state explicitly the conditions and requirements of the discharge. As an example, if performance criteria for downstream waters or biological surveys are to be included as permit requirements, they should be identified by parameters, have specific locations for compliance and be included in the monitoring program. The key to adequate review in the compliance phase of the permit process is specificity by the writer in setting permit requirements and conditions.

3.4 CONSTRUCTION GRANTS PROGRAM

3.4.1 Construction Grants Purpose and Background

The primary purpose of the Construction Grants (201) program is to assist communities in meeting the goals of the Clean Water Act by providing funds for wastewater treatment facilities. This program is authorized by Section 201 of the Clean Water Act. Wastewater facilities planning, design and construction are Steps 1, 2 and 3 of the Construction Grants program, respectively. These three steps take place in consecutive order, as shown in Figure 3-5, except when Steps 2 and 3 are blended together as one step. Communities potentially eligible for a construction grant are assigned a position on the state's priority list by the appropriate state agency. Priority is based primarily on the extent of existing documented water quality and/or public health concerns. States may add other factors into the priority formula which could affect the position of the project on the priority list (e.g., Kentucky intends to add an operational factor in the formula which will give credit to applicants with demonstrated good plant operation).

The importance of the Construction Grants program to the use of wetlands for wastewater management currently is limited for the following reasons:

1. Funding for the program has been reduced
2. With limited funds, only the highest priority projects obtain funding, and most small communities are low on the priority list
3. Lack of wetlands-specific guidelines
4. The use of funds for the purchase of a wetland is applied inconsistently.

Regardless of current funding levels, the Construction Grants program is potentially valuable because of its planning requirements and guidance. Primary among facilities planning requirements are the cost-effectiveness analysis guidelines that address the requirements of developing, evaluating and selecting cost-effective wastewater management alternatives.

Based on recent amendments to the program, separate Step 1 and Step 2 grants are no longer given; instead, allowances are included in the Step 3 grant for facilities planning and design activities (EPA 1982). Financial advances for the Step 2 grant may be obtained by small communities from the state environmental agency. Any municipality that received a Step 1 grant prior to December 29, 1981, will complete the facilities planning process according to its original grant agreement. Step 2 plus 3 or Step 3 grants must meet the requirements of the amendments.

Permit compliance options for wetland discharges include the following:

- Increase the level of EPA/state compliance inspections for wetlands discharges

  Significant Features
  - Improves the ability of regulatory agencies to assure protection of wetland functions and values
  - Acknowledges that uncertainties may exist with wetland wastewater management systems
  - Enhances ability to detect significant changes to wetland functions or values
  - Would increase the knowledge base concerning wetland responses to wastewater discharges

- No change

  Signficant Features
  - May not be sufficient to protect wetland functions and values

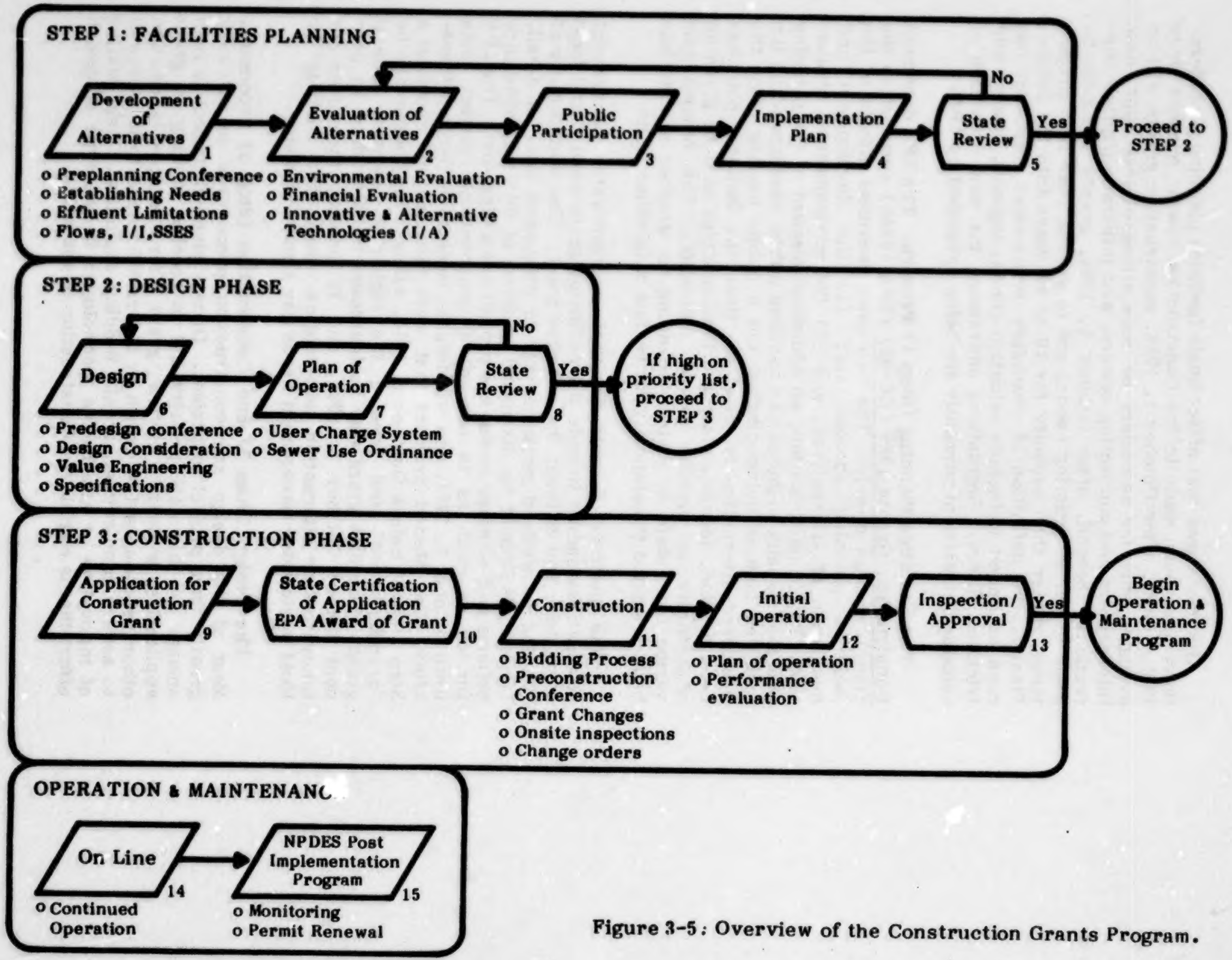
STEP 1: FACILITIES PLANNING
Development of Alternatives
1
o Preplanning Conference
o Establishing Needs
o Effluent Limitations
o Flows, I/I,SSES
Evaluation of Alternatives
2
o Environmental Evaluation
o Financial Evaluation
o Innovative & Alternative Technologies (I/A)
Public Participation
3
Implementation Plan
4
State Review
5
No
Yes
Proceed to STEP 2
STEP 2: DESIGN PHASE
Design
6
o Predesign conference
o Design Consideration
o Value Engineering
o Specifications
Plan of Operation
7
o User Charge System
o Sewer Use Ordinance
State Review
8
No
Yes
If high on priority list, proceed to STEP 3
STEP 3: CONSTRUCTION PHASE
Application for Construction Grant
9
State Certification of Application EPA Award of Grant
10
Construction
11
o Bidding Process
o Preconstruction Conference
o Grant Changes
o Onsite inspections
o Change orders
Initial Operation
12
o Plan of operation
o Performance evaluation
Inspection/ Approval
13
Yes
Begin Operation & Maintenance Program
OPERATION & MAINTENANC
On Line
14
o Continued Operation
NPDES Post Implementation Program
15
o Monitoring
o Permit Renewal

Figure 3-5: Overview of the Construction Grants Program.

Other changes that affect basic facilities planning considerations have been made to the Construction Grants process since 1981. First, after October 1, 1984, construction grants will be available only for secondary or more stringent treatment, new interceptors and connecting sewers, and infiltration/inflow corrections. Second, after October 1, 1984, grants will only be made to handle existing needs, not to exceed year 1990 projections, rather than capacity for 20 to 40 years into the future. Finally, the definition of secondary wastewater treatment has been expanded to include oxidation ponds, lagoons, ditches and trickling filters. Regulations addressing the new definition of secondary treatment currently are being developed by EPA.

The Facilities Planning (Step 1) Process. The EPA document Construction Grants 1985 (CG-85) (EPA 1984b) summarizes the Step 1 process clearly. The two basic technical efforts of the facilities planning process are: (1) the development and evaluation of alternatives, and (2) the environmental evaluation. Public participation, an additional element of the planning process, usually includes two to three public meetings while the facilities plan is being drafted and a public hearing after the preferred alternative is selected. Once the facilities plan has been drafted, federal, state and local agencies must be given an opportunity to provide review comments. The federal role varies from state to state, depending on whether a state has been delegated the authority for review of facilities plans.

The analysis of costs for various wastewater management alternatives should include the estimated grant amount and local costs with and without the possible grant. The applicability of funding to wetland projects will be discussed later in detail. Local costs should be discussed in terms of EPA's affordability criteria and whether or not the project has a high cost. The EPA funded as much as 75 percent of grant-eligible project costs until October 1, 1984, and will fund as much as 55 percent thereafter. For phased projects that were initiated and received a Step 3 grant before October 1, 1984, subsequent phases may be "grandfathered" and receive the higher 75 percent federal grant. The EPA grant may be increased to as much as 85 percent before October 1, 1984, and 75 percent thereafter for innovative or alternative technologies. Some state funding for local wastewater management needs may also be available.

The Design (Step 2) and Construction (Step 3) Processes. Most of the design and construction procedures do not vary greatly from project to project. Once a planned project is high enough on the state priority list to receive funding, a grant application, state/EPA review, grant offer and acceptance, and other procedures (as shown in Figure 3-5) need to be followed to assure construction grants funding eligibility. Field testing of innovative or alternative technologies is one type of design effort that is eligible for Construction Grant funds.

The development of construction specifications, a plan of operation and an operation-maintenance manual are prerequisites for the award of a Step 3 grant. Construction specifications can include methods to minimize wetland disturbance, erosion and sediment control techniques and requirements to avoid activities within a wetland during certain time periods, if appropriate. Other types of mitigative and enhancement measures can also be included. Considerations for construction, start-up and operation are included in the required plan of operation. Start-up and maintenance procedures associated with the use of wetlands can be included in the required operation and maintenance manual.

Monitoring of construction activities also must be provided by the local wastewater/public works agency or by a consultant. Following construction, one year of engineering services must be provided to supervise and train operators and to troubleshoot serious problems that the operators are unable to solve.

3.4.2 Construction Grants Program Requirements and Current Practices

The Construction Grants (201) program is divided into four general phases as depicted in Figure 3-5. Its purpose is to provide federal funding for the planning (activities 1-5), design (activities 6-8), construction (activities 9-13) and start-up (activities 14-15) of wastewater management facilities. Currently, however, no wetland specific guidelines have been issued as part of the program. Table 3-6 summarizes the current Construction Grants practices concerning wetlands discharges in the Region IV states. If wetlands are part of a wastewater management plan, eligibility for and level of federal funding, ownership or control requirements and cost effectiveness analyses should be assessed.

Each state is allocated a portion of the federal budget designated for the Construction Grants Program. The program is implemented on the state level, but all plans must be reviewed and approved by the EPA prior to the applicant receiving a grant unless the program has been delegated to the state. In Region IV, the 201 Program has been delegated to all eight states. Each state must certify the 201 Plan and then prepare the draft Finding of No Significant Impact (FNSI) for EPA's review, approval and distribution. EPA performs these tasks for states that have not been delegated 201 responsibility.

All states are responsible for establishing a priority list which determines the order of importance of wastewater management problems within the state and, therefore, the order of funding. Projects are funded based on this priority list and the amount of funds available. Under current budget conditions,

Table 3-6. Summary of Current State Practices Associated with the Construction Grants Program

State	Wetland-specific guidelines as part of facilities planning? Activity 1	Access or control of wetland required? Activity 1	Have applied I/A designation to wetlands discharge? Activity 2	Have wetlands-specific environmental review components function? Activity 2	Have required special construction practices for wetlands discharges? Activity 11
Alabama	-	X	-	-	-
Florida	-	-	-	-	-
Georgia	-	-	-	-	-
Kentucky	-	-	-	-	-
Mississippi	-	X[1]	-	-	-
North Carolina	-	-	-	-	-
South Carolina	-	X	-	X	-
Tennessee	-	-	-	-	-

---

[1] Required only if wetland is needed for wastewater renovation; if assimilation (disposal) only, access or control is not required.

only a limited number of projects on the priority list realistically can be funded. The result is a long list of applicants (over 200 applicants in some Region IV states) who will not receive funding.

Some projects can receive funds for Innovative and Alternative (I/A) wastewater systems even though they are not ranked high on the priority list. A 4 percent I/A set-aside is provided in each state for I/A projects. This is a major incentive when considering I/A systems. In addition, a higher percentage of project funds can be obtained for I/A projects.

3.4.3 Construction Grants Wetland Discharge Considerations

Facilities planning issues include siting, estimating discharge characteristics, evaluating alternatives, assessing specific environmental impacts and financing. Chapter 3 presents a detailed assessment of most of these elements. Engineering design, construction, operation and maintenance, and mitigation are addressed by Chapters 6 and 7. Several issues, however, affect the applicability of the Construction Grants program to wetlands discharges. All discussions of the applicability of the Construction Grants program assumes the proposed project has a sufficiently high priority to be funded. Otherwise, the Program has little influence, although 201 guidelines potentially could provide useful information for planning and implementing a wetlands discharge.

The issues requiring attention are:

1. **Incorporation of wetland specific components into the Construction Grants Program**
2. **Funding of wetlands for wastewater management**
3. **Extent of wetlands control required for funding.**

3.4.4 Alternatives for Construction Grants Wetland Discharge Considerations

Three major issues have been raised in the previous section concerning the applicability of the Construction Grants program to the use of wetlands for wastewater management. The main element of the Construction Grants program is funding; therefore, interpretations concerning funding of wetlands wastewater systems are probably the most important. The other important aspect of the program is the guidance provided for planning, designing and evaluating wastewater management alternatives. Guidance provided on wetlands-specific elements could be helpful to an applicant regardless of funding if the program guidelines adequately consider wetlands systems.

Consideration 1--

Wetland Specific Components Incorporated into Construction Grants Guidelines. Construction Grants (CG) Guidelines provide the basis for assessing wastewater management projects. Not only do the Guidelines outline the tasks that should be conducted by the applicant to evaluate wastewater management alternatives, they also are the basis for regulatory decision making. Presently, CG Guidelines do not specifically address the use of wetlands for wastewater management. Components for which guidance is needed for wetlands-wastewater management include:

1. Engineering options
2. Alternatives evaluation
   - Environmental effects
   - Costs
   - Implementability
   - Operability
3. Access/Control
4. Construction
5. Operation and Maintenance

Technical guidance for each of these components is provided by subsequent sections of the Handbook.

One of the important aspects of the Construction Grants program has been the assessment of environmental impacts, as mandated by NEPA for wastewater management projects receiving federal funds. This asessment has been the primary mechanism for reviewing the potential environmental impacts of wastewater management alternatives and has been an important consideration in the selection of the preferred alternative. For communities meeting their wastewater management needs independent of the Construction Grants program, an environmental review may not be required but remains valuable. The following wetlands-specific components could be applicable to the environmental review procedures of the Construction Grants program.

Planning

Land use in the watershed
Modifications to the wetland (e.g., road through wetlands, construction in wetlands)
Development trends and secondary impacts
Wetland ownership and access
Funding sources and requirements
Existing uses of wetland
Cultural resources
Recreation/Aesthetics

Geomorphology

Soils types
Substrate (e.g., Karstic areas)
Proximity to other wetlands
Wetlands boundaries
Wetland type and size

Hydrology

Water budget
Hydroperiod
Hydrologic interconnections
Sensitivity to alterations

Water Quality

Basic analyses
- Dissolved oxygen
- pH
- Suspended solids
- BOD
- Fecal coliforms

Elective Analyses
- Color
- Metals
- Nutrients (C,N,P)
- Alkalinity
- Total coliforms
- Fecal streptococci

Seasonal fluctuations (e.g., nutrient uptake vs. release)
Sensitivity to alterations (e.g., pH in bogs)
Assimilative capacity (involves soils vegetation, hydrology)

Ecology

Vegetation species composition
Protected species habitat
Wildlife habitat
Waterfowl breeding and habitat
Value to downstream habitats
Sensitivity to alterations
Elective ecological analyses

If CG Guidelines are expanded to provide specific guidance for wetlands wastewater systems, regulatory agencies and applicants could use these guidelines regardless of whether Construction Grant funds are involved. Other elements such as design of discharge structures and back-up systems, construction practices and operation and maintenance could be addressed by Construction Grants guidelines to assure wetlands discharges are properly considered.

The following alternatives address the incorporation of wetland specific components into Construction Grants guidelines.

- o Modify CG guidelines to address wetlands specific issues

  Significant Features
  - Requires development and adoption of guidelines
  - Would improve consistency in considering wetland-wastewater projects
  - May have limited influence on wetland projects due to limited number of potential wetland projects which will be funded
  - Elevates the knowledge base of wetlands wastewater management

- o Develop technical guidance for considering wetland-wastewater projects

  Significant Features
  - Provides flexibility to states that administer CG Program
  - May be useful for cases where CG funding is not involved
  - Would improve consistency in considering wetland projects
  - Elevates the knowledge base of wetlands wastewater management

- o Use the Freshwater Wetlands for Wastewater Management Handbook to provide needed guidance

  Significant Features
  - Could provide the basis for additional CG specific guidance
  - Addresses the interrelationships of CG, NPDES and WQS issues
  - As additional information becomes available, programs change and issues become resolved, the Handbook will periodically be updated
  - Portions of the Handbook are specific to Region IV

- o No change

  Significant Features
  - Retains void in CG review process and guidelines for wetlands wastewater systems
  - Provides no guidance for considering wetlands wastewater systems

Consideration 2--

Funding of Wetlands for Wastewater Management. Funding land purchases through the Construction Grants program is dependent on the land being an integral part of the treatment process. Standards must be met at the point of discharge to the wetland where wetlands are waters of the U.S. Because of the current interpretation that waters of the U.S. cannot be part of the treatment process even if water quality standards are met while providing treatment, wetlands cannot be purchased with CG funds. The issue of funding other parts of a wastewater management plan through the Construction Grants program is discussed with the next issue.

In examining practices throughout the country, other interpretations of the funding issue are noted. In Oregon, for example, a natural wetlands discharge apparently has been considered part of the treatment process, and funding of the project has proceeded. Implementation of the project was tied closely to monitoring wetland impacts. In Iowa, a natural wetlands discharge has apparently been considered part of the treatment process and received funding under the Innovative and Alternative Technologies (I/A) program. Other examples of funding wetlands purchase as part of the treatment process also exist.

In Region IV, funding has not been made available for wetlands purchase, but ownership may be essential to funding the remainder of the project. This simply means that ownership must be obtained by other funding sources or land acquisition options. The EPA Assistant Administrator for Water issued a memorandum denying funding eligibility for the purchase of a wetland in South Carolina. The ramifications of this as it applies to other cases are not yet clear. This could result in a disincentive for wetlands wastewater systems compared to other wastewater management alternatives.

While funding through the CG program may be an important issue to some communities, many communities wanting to use wetlands for wastewater management will not be high enough on the state priority list to receive Construction Grant funding. Other state and regional funding sources (e.g., community development block grants) might be available, but their policies concerning the necessity of ownership and the eligibility of purchasing the wetland would need to be investigated.

Options available for the funding of wetlands for wastewater management follow.

- o Reconsider Construction Grants eligibility for wetlands providing pollutant removal necessary to meet downstream standards

  Significant Features
  - Requires a new interpretation from EPA's Office of Water Programs concerning funding treatment facilities
  - Provides a mechanism for recognizing wetlands' ability to renovate wastewater
  - Depending on the interpretation, funds for wetlands purchase might be allowed
  - If CG funds were available, the use of wetlands, where feasible, could be promoted
  - Would require regulations changes concerning waters of the U.S.
  - I/A funding may be available

- o No change

  Significant Features
  - Discourages wetlands use when CG funds are available
  - Seems inconsistent with land treatment funding policy
  - Avoids problems associated with land purchases through the CG program

Consideration 3--

Extent of Wetlands Control Required for Funding. Based on EPA's current position, wetlands are not considered part of the secondary treatment process; therefore, their purchase cannot be funded as part of the Construction Grants Program. A wetland discharge, however, still can be part of a wastewater management plan. The pertinent question is, then, "What extent of wetlands control or access is necessary for a project to receive Construction Grants funding?" Demonstrated control or access to a wetland may be necessary for a wetlands wastewater management project to be grant eligible, even though purchase of the wetland is not grant eligible.

In South Carolina, ownership of the wetland is necessary to demonstrate control. Therefore, purchase of the wetland is required regardless of whether Construction Grants funding is sought. Alternatives to obtaining land through direct purchase are land donations or land exchanges. In states where purchase is not necessary, demonstrated control might be achieved through long-term leases or rights-of-way. Construction Grants guidelines stress the need for assured control or access of all land associated with the wastewater management plan. This is the reason control is required by some states independent of the Construction Grants program. The importance of wetland control is related to assuring wetland integrity and assimilation are maintained. Without control, a property owner

potentially could alter a wetland's uses and, therefore, reduce the system's assimilative capabilities.

The following options should be evaluated when considering the extent of wetland access or control required for CG funding.

- **Require control in order to receive CG funds**

  Significant Features
  - **Assures long-term access to wetland**
  - **Could be essential to wetlands maintenance**
  - **Control may require ownership**
  - **If purchase/easement is not funded by CG program, it could cause local funding problems and discourage wetlands use**

- **No change**

  Significant Features
  - **If control is currently required or promoted, few difficulties associated with no change**
  - **If control is not currently required or promoted, no change could result in difficulties with multiple use characteristics of wetlands**
  - **Failure to maintain wetland could result in revocation of permit or development of new effluent limits**

3.5 USER'S GUIDE

The Chapter 3 User's Guide is intended to highlight the major institutional issues and provide guidance for decision making. This Handbook is designed to present the major issues and some of their solutions, so that programs regulating the use of wetlands for wastewater management might be more efficient, comprehensive and consistent. The objectives of the Clean Water Act form the foundation for the guidance provided.

The User's Guide is divided into the three program areas discussed in the chapter: Water Quality Standards, NPDES Permits and Construction Grants. Technical support for addressing the issues presented is found in subsequent chapters. These are cross-indexed where appropriate for easy access.

While the primary user of the User's Guides in Chapters 4, 6 and 7 is a potential discharger, **this guide is designed primarily for regulatory agency personnel** and includes:

1. Presentation of the major issues identified for each of the three major wastewater management regulatory programs

2. Questions to assess the pertinence of that issue to each state regulatory program

3. Potential alternatives to help resolve ambiguities or lack of program guidance.

Figure 3-6 provides an overview of the decision making process for any wastewater management system. Highlighted on the figure are the wetlands-specific considerations that should be assessed. The NPDES permitting process is the common denominator of any discharge to waters of the U.S., regardless of Construction Grants eligibility. The permitting process is the practical application of the WQS program to a wastewater discharge. Therefore, if consistent procedures for evaluating, planning, designing and protecting wetlands-wastewater systems are desired, each of these components must be addressed by regulatory programs. If a wastewater project is not involved with the Construction Grants program, and associated guidelines, one of the other pertinent regulatory programs should provide such guidance.

Forms 3-A, 3-B and 3-C summarize the issues raised for each regulatory program and provide an outline for assessing the relevance of the issue and potential alternatives for providing regulatory guidance. Ultimately, three major options exist for resolving outstanding issues:

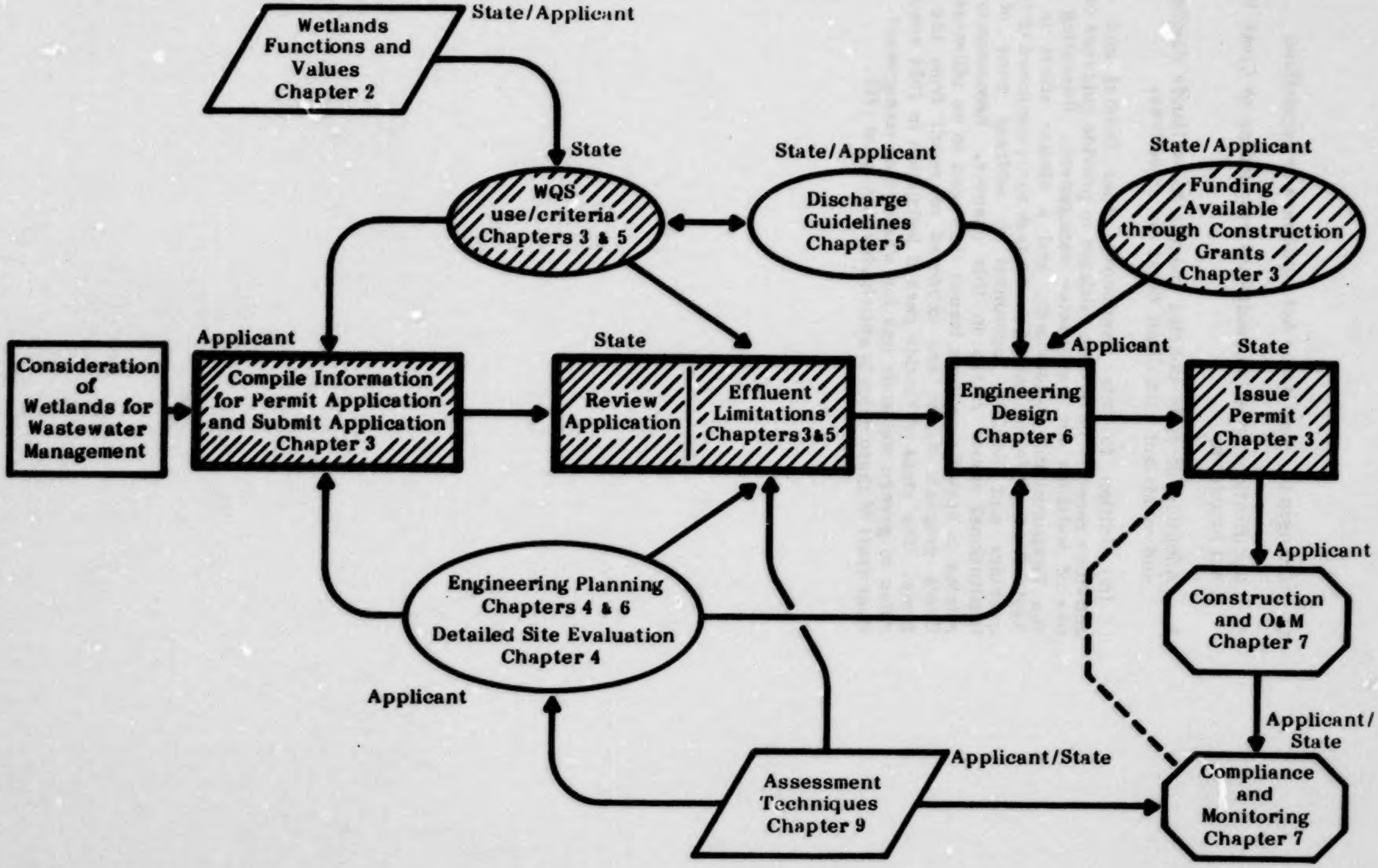
Wetlands Functions and Values Chapter 2
State/Applicant
State
WQS use/criteria Chapters 3 & 5
State/Applicant
Discharge Guidelines Chapter 5
State/Applicant
Funding Available through Construction Grants Chapter 3
Consideration of Wetlands for Wastewater Management
Applicant
Compile Information for Permit Application and Submit Application Chapter 3
State
Review Application
Effluent Limitations Chapters 3 & 5
Applicant
Engineering Design Chapter 6
State
Issue Permit Chapter 3
Applicant
Construction and O&M Chapter 7
Applicant/State
Compliance and Monitoring Chapter 7
Engineering Planning Chapters 4 & 6
Detailed Site Evaluation Chapter 4
Applicant
Assessment Techniques Chapter 9
Applicant/State

Figure 3-6. Relationship of the Handbook to the Decision Making Process.

1. Changes in Clean Water Act guidelines or regulations
2. Modifications of state guidelines responding to Clean Water Act programs
3. Adoption of state policies specific to wetlands discharges and consistent with Clean Water Act objectives.

In addition to this Handbook, other federal and state activities recently have been initiated to provide guidance on the use of wetlands for wastewater management. Emanating from the Environmental Assessment, and a similar effort in EPA Region V, the EPA has established a task force composed of Headquarters and Regional personnel to address many of the institutional issues raised in this chapter. Recommendations related to specific program issues that need to be addressed by EPA's program offices are expected to result from the task force. The state of Florida passed legislation in 1984 requiring rules to govern wetlands use for wastewater management. The first draft of these rules is anticipated in August 1985.

REGULATORY PROGRAM ALTERNATIVES ASSESSMENT

FORM 3-A. Summary of Water Quality Standards Program Considerations

Consideration 1--Incorporation of wetland functions and values into water quality standards use classifications.

- Adopt a new WQS wetland use classification that broadly addresses all wetland functions and values
- Adopt new use classifications based on specific uses that are not currently protected for wetlands (e.g., flow regulation, water purification)
- Use wetland subcategories under existing use classifications
- No change (use natural waters clause)

Consideration 2--Parameters to support wetland uses or subcategories

- Use of physical parameters
- Use of biological parameters
- Use of chemical parameters
- No change

Consideration 3--Types of criteria to support wetland parameters

- Adopt numeric criteria
- Adopt narrative criteria
- Adopt a combination of numeric and narrative criteria
- Adopt seasonal criteria
- Adopt minimum, maximum and/or average guidelines for numeric criteria
- No change

Consideration 4--Establishment of wetland specific standards

- Establish use subcategory with generic narrative and/or numeric criteria
- Establish use or subcategory and site-specific criteria where generic narrative or numeric criteria are not appropriate
- No change (i.e., no new use classification, employ site-specific criteria or invoke natural waters clause)

Consideration 5--Designation of wetland standards.

- Designate wetland use classifications or subcategory on National Wetlands Inventory mapping or other wetlands inventory system
- Designate wetland use classification or subcateogry on a site-specific basis
- Use existing "natural waters" clause
- No change

Does your state currently have standards criteria (generic) specifically for wetlands? Yes ____ No ____

If yes, does this alleviate the need to apply site-specific criteria? Yes ____ No ____

Is your current policy to require site-specific standard analyses for potential wetland discharges? Yes ____ No ____

Would the process of defining standards criteria for wetlands be made more efficient if guidelines for determining site-specific standards were established? Yes ____ No ____

Which existing use classification most closely represents wetlands?

____

What are the main uses or functions protected by this use classification?

____

What other important functions of wetlands are under your jurisdiction?

____

____

FORM 3-A. Continued

Would protecting these uses or functions be consistent with the intent and goals of the Clean Water Act? ______________________________

____

If the answer to the last question of the assessment is yes, you may need to consider either a new use classification or a use classification modifier to define wetlands fully and protect them as waters of the U.S.

Have wetlands-related criteria been developed for your state? Yes ____ No ____

What are the criteria currently applied to wetlands?

____

____

Do these criteria protect the major wetlands functions and uses that have been identified? (See Chapter 2.) ______________________________

What parameters define wetland functions and uses for which criteria are needed?

____

____

What criteria could be instituted to support wetland use classifications? (See Chapter 5.) ______________________________

____

FORM 3-8. Summary of NPDES Permit Program Considerations

Consideration 1--Additional Permit Information

- Use the Standard Form A NPDES permit application for any potential wetlands discharge, regardless of size
- Modify all NPDES permit application forms to include a map displaying proposed discharge location
- Modify all NPDES permit application forms to include wetlands discharge information
- Modify existing review procedures to require additional wetland discharge information
- Establish tiered approach for obtaining information based on loading rate and wetland type
- No change

Consideration 2--Potential Effluent Limitation Parameters

- Adopt wetlands-specific guidelines for use of physical parameters (e.g., velocity, hydraulic loading rates, etc.)
- Adopt wetlands-specific guidelines for using chemical parameters (e.g., DO, nutrients, pH)
- Use combination of physical, biological and chemical parameters
- No change

Consideration 3--Techniques for Determining Effluent Limitations for a Wetlands Discharge

- Classify all wetlands effluent-limited, requiring secondary treatment, unless other major discharges exist
- Use a tiered approach of establishing effluent limits based on loading rates
- Adapt currently used models or use more sophisticated models to establish effluent limits for wetland discharges
- Develop a standard method for performing qualitative analyses
- No change

Consideration 4--Wetland Specific Permit Requirements/Conditions

- Use of prescribed levels of pretreatment
- Use of seasonal operational requirements
- Use of implementation schedule
- Use of monitoring and reporting requirements
- Use of ownership or access requirements
- Use of in-stream performance criteria
- No change

Consideration 5--Permit Compliance for Wetlands Discharges

- Increase the level of EPA/state compliance inspections for wetlands discharges
- No change

Have guidelines been established for defining what is or is not a wetlands discharge? (See chapter 4.) Yes _____ No _____

Do you require additional information on a permit application for a wetland discharge? Yes _____ No _____

If yes, what information is required?

____

____

Do you impose additional compliance constraints or permit conditions for a wetlands discharge? Yes _____ No _____
If yes, what are they?

____

____

FORM 3-B. Continued

What methods are currently used in your state to obtain effluent limitations for wetlands discharges?

What modifications have you made to conventional modeling applications?

What comprises an on-site wetlands assessment?

How are analyses used to establish effluent limitations?

What is the procedure for establishing limits for parameters not addressed by standards (e.g., nutrients, metals, etc.)?

Do you establish permit conditions for parameters not addressed by water quality standards? Yes ____ No ____
If yes, what parameters? ____

Has your state established policies or guidelines for assessing parameters or functions that are important to wetlands protection? Yes ____ No ____

Must permit requirements currently be met at the point of discharge to the wetlands or from the wetland? To ____ From ____ Both ____

Do you allow variances in permitting wetlands discharges? Yes ____ No ____

Do you delineate a wetlands mixing zone which is exempt from meeting standards? Yes ____ No ____

Have the assimilative or treatment capacities of wetlands been incorporated into the engineering design of any wetlands discharge in your state? Yes ____ No ____

Have any wetlands in your state not been classified as waters of the U.S.? Yes ____ No ____

Since most wetlands are waters of the U.S., they are to be afforded all the associated protective measures. As such, permit conditions must be met at the point of discharge to the wetland.

Is any amount of change acceptable as long as the wetland remains viable? Yes ____ No ____

Are any wetland changes acceptable? Yes ____ No ____

Has this issue been addressed by your state regulatory guidelines or policies? Yes ____ No ____

Does the wetland being considered for a wastewater discharge have any other direct pollutant sources? Yes ____ No ____

FORM 3-B. Continued

Does the wetland have any indirect pollutant sources? Yes ____ No ____
If yes, how many and how much flow?

____

____

Is the wetland classified the same as its adjoining stream segment? Yes ____ No ____

If so, does the classification adequately characterize the wetland? Yes ____ No ____

____

FORM 3-C Summary of Construction Grants Program Considerations

Consideration 1--Incorporation of Wetland Specific Components

- Modify CG guideinles to address wetlands specific issues
- Develop technical guidance for considering wetland-wastewater projects
- Use the Freshwater Wetlands for Wastewater Management Handbook to provide needed guidance
- No change

Consideration 2--Funding of wetlands for wastewater management

- Reconsider Construction Grants eligibility for wetlands providing pollutant removal necessary to meet downstream standards
- No change

Consideration 3--Extent of wetlands control required for funding

- Require control in order to receive CG funds
- No change

Has a wetlands-wastewater project in your state applied for funding? Yes _____ No _____

Have Construction Grants funds been used for any wastewater management project in your state involving wetlands? Yes _____ No _____ If so, what aspects of the project were eligible for funding? _____

Has the proposed use of wetlands been for treatment _____ or disposal _____ of wastewater?

Has your regulatory agency encountered any problems in the purchase of land as part of a wastewater treatment process? Yes _____ No _____

Have sources other than the Construction Grants Programs been sought for funding a wetlands wastewater project in your state? Yes _____ No _____

What current aspects of CG Guidelines directly pertain to wetlands?

Are wetlands-specific design options delineated? Yes _____ No _____

If yes, what are they? _____

Are environmental review components related to wetland ecosystems provided in sufficient detail to review a wetlands-wastewater system? Yes _____ No _____

What mechanism is available for evaluating the plans of a wetlands-wastewater system other than the Construction Grants program?

What guidance is currently available to guide an applicant in planning and designing a wetlands-wastewater system?

What guidance is available for a community not eligible for Construction Grants funding? _____

What are the current environmental review components outlined by CG Guidelines that apply to wetlands? _____

Form 3-C Continued

Do these provide information on the full range of potential impacts to a wetland? Yes _____ No _____

If not, what components should be included?

____

____

Based on existing guidelines, can a wetland-wastewater system currently be planned and designed in conjunction with environmental concerns? Yes _____ No _____

If a community's project is not grant-eligible, what environmental guidance is provided by other programs for the design and protection of wetlands-wastewater systems?

____

What extent of wetland control is required by your state? _______________

____

Does your state require purchase of all wastewater discharge and treatment components? Yes _____ No _____

Is it important whether the land is used for disposal or treatment? Yes _____ No _____

What are the funding sources available for purchase? _______________

____

How are the boundaries or area requirements of land purchases determined?

____

What alternatives to purchase are acceptable for exercising control of land?

____

____

4.0 SITE SCREENING AND EVALUATION

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  - o Soils Characteristics
- **4.4.3 Wastewater Assimilation and Long-term Use Potential**

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4.0 SITE SCREENING AND EVALUATION

Who should read this chapter? Anyone involved with evaluating potential wetland sites for a wastewater discharge.

What are some of the issues addressed by this chapter?

- How can wetlands be assessed for their use in wastewater management?
- What components comprise wetlands site screening and evaluation?
- What level of analyses are reasonable?

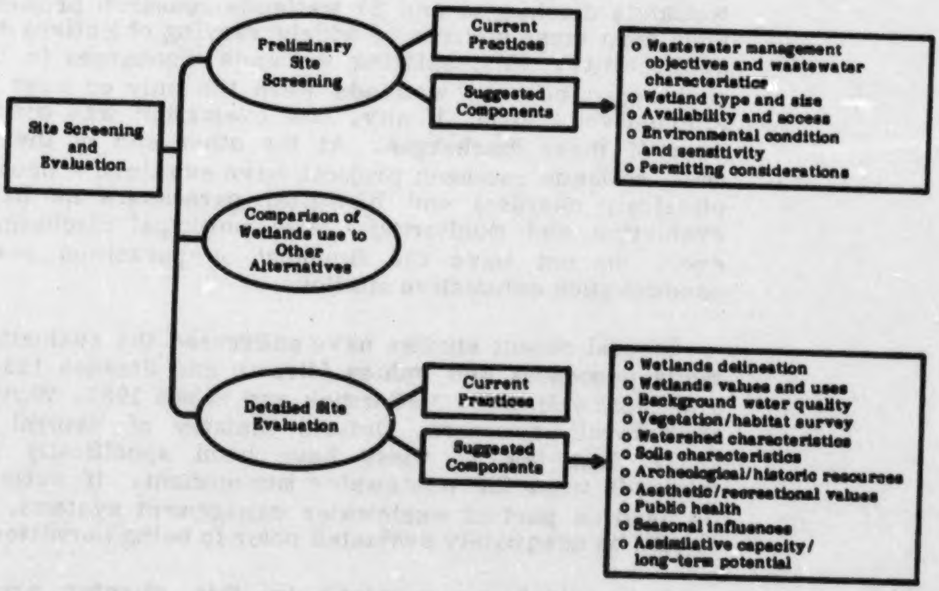

Site Screening and Evaluation
Preliminary Site Screening
Current Practices
Suggested Components
o Wastewater management objectives and wastewater characteristics
o Wetland type and size
o Availability and access
o Environmental condition and sensitivity
o Permitting considerations
Comparison of Wetlands use to Other Alternatives
Detailed Site Evaluation
Current Practices
Suggested Components
o Wetlands delineation
o Wetlands values and uses
o Background water quality
o Vegetation/habitat survey
o Watershed characteristics
o Soils characteristics
o Archeological/historic resources
o Aesthetic/recreational values
o Public health
o Seasonal influences
o Assimilative capacity/ long-term potential

Figure 4-1. Overview of Site-Screening and Evaluation

4.1 RELATIONSHIP TO INSTITUTIONAL, SCIENTIFIC AND ENGINEERING PRACTICES

The screening and evaluation of potential wastewater treatment facilities and disposal sites are essential elements of any wastewater management project. Wetlands-specific guidance for site screening and evaluation is limited although policies and procedures governing the use of wetlands for wastewater management are now developing. As guidelines are developed, they must incorporate the objectives of the Clean Water Act, particularly concerning water quality standards and antidegradation.

This chapter describes what parameters could compose preliminary and detailed site screening analyses, why they are important to the decision making process and when or under what circumstances the screening and evaluation elements apply. Of equal importance is how the analyses should be conducted; these technical elements are described in Chapter 9. The Chapter 4 User's Guide provides guidelines for assessing each aspect of preliminary and detailed site screening.

Few comprehensive, long-term studies offer technical guidelines. Two potential sources of information are: 1) existing wetlands discharges and 2) wetlands research projects. Guidance from these sources of widely varying objectives has limited applicability. Most existing wetlands discharges in the Southeast began because wetlands were the only or most accessible alternative. Little, if any, site evaluation was conducted for most of these discharges. At the other end of the spectrum, most wetlands research projects have examined a broad range of physical, chemical and biological parameters as part of site evaluation and monitoring. Most municipal dischargers, however, do not have the financial or personnel resources to conduct such exhaustive studies.

Several recent studies have addressed the evaluation of **wetlands processes and values** (Brown and Starnes 1983, Adamus and Stockwell 1983, McCormick and Somes 1982, Michigan Dept. of Natural Resources, Ontario Ministry of Natural Resources 1983), but few of these have been specifically applied to wetlands used for wastewater management. If wetlands are to be used as part of wastewater management systems, their uses should be adequately evaluated prior to being permitted.

The guidelines proposed in this chapter are designed primarily to meet permitting and water quality standards objectives and are based on existing knowledge of wetlands systems used for wastewater management. This chapter also addresses several facets of engineering planning. The components of engineering planning that do not influence directly the evaluation and selection of a wetlands site are described in Chapter 6.

The first step in evaluating a site is **preliminary site screening.** The intention is to provide a relatively quick and cost-effective procedure for determining when the use of a wetland site does not appear to be appropriate nor feasible.

If the wetlands alternative appears to be feasible after the preliminary screening, the most common or immediate obstacles do not preclude discharging wastewater to wetlands. The **comparison of the wetlands alternative** with the other potential alternatives should then be conducted. This includes a comparision of costs, operation and maintenance, long-term viability, monitoring and permit requirements (including effluent limitations). If the wetlands alternative still appears feasible, a **detailed site evaluation** may be warranted. Although this evaluation might indicate that the wetlands alternative is not feasible, many obstacles at this level can be overcome by mitigation. Figure 4-1 provides an overview of the site-screening process.

The use of indicator parameters (selected parameters that clearly and simply depict conditions) would be desirable for wetlands assessments. At this time, a technically-sound basis for the use of indicator parameters is not available. However, this chapter, by dividing site screening into preliminary and detailed phases, attempts to identify the critical components and provide an evaluation mechanism that is straightforward and only as complicated as the conditions being evaluated. The parameters identified in these phases are those critical to decision making, engineering planning and wetlands protection.

The ultimate selection of a wetland site depends on meeting the minimum requirements established for the three major topical areas: institutional, scientific and engineering. Site-selection is not based on any one of these, but all three. Limitations in any one area (e.g., permitting difficulties, habitat for endangered species, insufficient wetland area for wastewater distribution) can result in a potential wetlands site being considered not feasible or inappropriate. Therefore, equal attention is required to each area.

The concept of a tiered approach to evaluating wetlands discharges is presented in Section 3.3.4. Its main purpose is to establish administrative and evaluative requirements commensurate with the degree of risk or uncertainty presented by a proposed wetlands discharge. Regardless of the proposed discharge, all site screening components should be conducted. The only impact of a tiered approach might be in determining the number of parameters evaluated and the extensiveness of analysis for the detailed site evaluation. The evaluation components are the same, but a Tier 2 discharge might benefit from or need to conduct a more detailed evaluation than a Tier 1 discharge. Table 3-4 summarizes the classification of Tier 1 and Tier 2 discharges. These potential differences are discussed with sampling program design in Section 9.2.

4.2 PRELIMINARY SITE SCREENING

This section provides a checklist of variables that will indicate readily if the wetlands alternative is not feasible. The determination of whether a wetland is feasible generally cannot be made until additional analyses have been completed. This approach provides a cost-effective means for conducting preliminary feasibility analyses such that significant obstacles are identified early in the planning process. The potential discharger can then direct resources to other alternatives if the wetlands alternative is judged to be infeasible.

The previous section indicated that screening and evaluation guidance is needed that recognizes and responds to objectives of the Clean Water Act. On a more practical level, engineering planning issues also are essential to the screening process and may impact the feasibility of using wetlands. Therefore, guidelines should incorporate not only the concerns of regulatory programs, but also engineering planning concerns such as size requirements, availability and access, wastewater characteristics and cost effectiveness.

4.2.1 Considerations and Current Practices

None of the Region IV states has specific guidelines for evaluating wetland wastewater discharge sites. Each state typically requires a site-specific analysis of a proposed wetlands discharge site. The composition of these site-specific analyses varies, so a standard list of parameters or procedures is not available. Regulatory agency personnel conduct the site-specific analyses, observing vegetation type, general watershed characteristics and existing conditions.

4.2.2 Screening Components

The preliminary screening process suggested by this Handbook involves analyses in six areas:

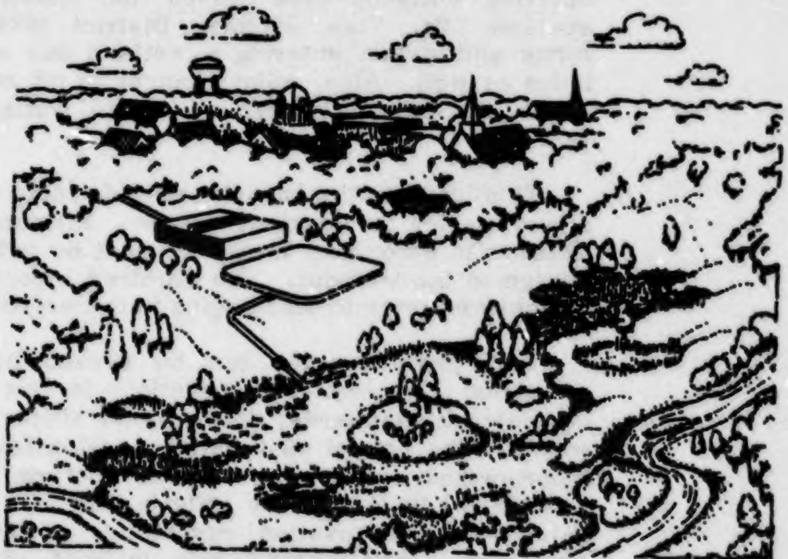
1. Wastewater management objectives and characteristics
2. Wetland type
3. Wetland size and topography
4. Wetland availability and access
5. Environmental condition and sensitivity
6. Permitting considerations.

Each of these has a fundamental influence on the feasibility or appropriateness of a wetlands discharge. If one component proves to be limiting, sufficient cause may exist to consider the wetlands alternative unacceptable. The discussion of each area of analysis is followed by a summary of potential limitations and their possible mitigation.

-- In the course of conducting preliminary site screening, a diagram of the proposed site with the approximate location of the treatment facility and conveyances should be prepared. Use of a topographic map is suggested. This should be helpful not only in visualizing considerations such as wetland access, but also in conducting the comparison of alternatives.

Wastewater Characteristics and Management Objectives. The first element of the screening process involves an assessment of wastewater characteristics and the role of wetlands in the wastewater management plan, as depicted in Figure 4-2.

Figure 4-2. Important Issues Addressed by Preliminary Site Screening



How much wastewater will be discharged?
What are wastewater sources?
What is the reason for using wetlands?
What type of wetland is being used?
How large is the wetland?
What area will be affected by the discharge?

Source: CTA Environmental, Inc. 1985.

Characterizing the wastewater influent to the treatment facility and the general quality of the wastewater effluent after treatment is important to planning and, ultimately, design decisions. This Handbook addresses only domestic municipal wastewater discharging to wetlands systems. If an influent contains large quantities of potentially toxic substances such as heavy metals, pesticides, herbicides, dyes or salts, then special care must be taken if a wetland is part of the wastewater management system. Pretreatment may be mandatory. The few cases of documented tree kills in wetlands resulting from discharges have been associated with industrial or commercial discharges. High concentrations of salts and solvents have been suspected of causing damage to wetlands into which they discharged (EPA 1983).

Even when wetlands are to be used primarily for domestic, municipal sewage, it is still important to characterize the effluent based on the type of treatment anticipated prior to discharging to the wetland. High levels of un-ionized ammonia entering wetlands have caused fish toxicity problems in some systems (Mt. View Sanitary District 1983). Other nutrient forms and metals entering a wetland can affect its characteristics as well. Also, major changes in pH resulting from wastewater can be detrimental to certain wetland systems (Kadlec 1985).

This leads to the importance of defining the wetland's role in a wastewater management system. Effluent limits based on a minimum of secondary treatment must be met at the point of discharge to the wetland. The required secondary treatment must be achieved prior to discharging to the wetland.

Two primary roles can be served by the wetland. If additional wastewater renovation is not required to meet downstream standards, the wetland simply acts as a receiving water. The normal assimilative capabilities of the wetland are incorporated into the standards criteria and effluent limits established to meet those criteria. In this instance, efforts to enhance the renovation capabilities of the wetland are not necessary. The second role is that of seeking additional renovation or treatment. Standards criteria still must be met in the wetland. But if downstream waters have more stringent standards criteria for certain parameters, e.g., nutrients, the wetland could be used to achieve this additional polishing. In such a case, system design might be tailored to enhance the nutrient removal capacity of the wetland. Therefore, it is important to define what role the wetland will serve in the wastewater management scheme.

Following are some of the major limitations to wetlands use which could be encountered in assessing wastewater characteristics. Potential mitigation options also are listed.

Wastewater Characteristics -
Major Limitations to Wetlands Use

Limitation	Potential Mitigation
1. Wastewater stream contains potentially toxic pollutants.	o Verifiable pretreatment or reject use of wetland site.
2. Wastewater flows may significantly alter the existing hydroperiod (seasonal water level fluctuations).	o Sufficient area to alternate discharging and resting. o Incorporation of seasonal fluctuations in operation schedule to match natural fluctuations. (e.g., storage of wastewater).
3. Water chemistry changes (e.g., pH) are detrimental to wetland viability.	o Alter water chemistry of effluent. o If not possible, reject wetland site.

Wetland Type. The identification of wetland type is a fundamental element in screening because so many other screening components depend on the characteristics of the wetland. Wetland sensitivity, uniqueness and wastewater management capabilities vary, and often are evaluated by wetland type. Identification of wetland type is not always straightforward and in many instances will require the assistance of a field biologist. Some state and federal agencies (particularly fish and wildlife resource agencies) have qualified personnel who can assist with wetlands identification. Additionally, Table 2-3 provides information on identified unique and endangered wetland types.

Classifying wetlands has been the subject of extensive study for many years. Different agencies have used different classification schemes for identifying wetland types. In recent years, more agencies have adopted the approach proposed by the Fish and Wildlife Service (Cowardin 1979). Many states still are using and developing techniques, however, that pertain specifically to the wetland types under their jurisdiction. For example, the state of Florida has developed a vegetation list for defining wetland boundaries and type. A variety of classification techniques continues to be used.

The Cowardin system is probably the most exhaustive technique of those currently available. The major determinant with this system is the predominant vegetation type (as it is with most classification schemes); other important determinants are soils and hydrology. Nearly all classification systems are based on a combination of these three characteristics. Simplified techniques relating to visual field analyses of soils, for example, are being developed in an attempt to make wetland classification easier.

How does the classification of wetlands relate to wastewater management issues? The ability of wetlands to accept a wastewater discharge varies significantly. Primarily, this ability is based on the hydrology and hydrologic sensitivity of wetlands. Some wetlands react poorly to the addition of flows that alter their hydroperiod (the normal water level fluctuations) or water chemistry. Table 8-3 lists some of the limitations of certain wetland types for receiving wastewater.

Since not all wetland types or wetlands react the same to wastewater additions, it is not prudent nor possible to make universal pronouncements concerning the acceptability of a certain wetland type for use under any conditions. For example, a cypress dome may be acceptable for use under some conditions but not others, depending on uses, hydrology, soils, hydrologic interconnections, water chemistry or habitat for endangered species.

On the other hand, it may be possible on a state-by-state basis to exclude a particular wetlands type for use based on distribution, uniqueness or sensitivity to additional flows. If, for example, a wetland type is unique to a state and only locally distributed, this wetland type might be considered unacceptable for use. State fish and wildlife agencies should be contacted to determine uniqueness and distribution. Section 2.4 indicates the unique or endangered wetland types identified by district Fish and Wildlife Service offices or state natural heritage programs for Region IV states.

Wetland Type -
Major Limitations to Wetland Use

Limitation	Potential Mitigation
1. Wetland type considered highly sensitive to added flows or changes in water chemistry.	o Maintain wastewater flows below those levels that are considered critical through the use of storage capability, multiple wetland cells or increasing the area of wetland to be used. o Select another alternative.
2. Wetland type locally distributed, only habitat for endangered species, considered unique.	o Pursue other alternatives; assess feasibility only if this is the sole alternative.
3. Acceptability of type uncertain due to lack of available information or knowledge of the system.	o Conduct a pilot project in a controlled area, as required by regulatory agencies, including assessment of hydrology, vegetation and water quality.

Wetland Size and Topography. If an acceptable wetland type is located near the community (e.g., within 1-10 miles, depending on size of flow), the size and topography of the wetland are the next considerations. Size is important since it controls the maximum flows that can be applied. Sufficient size to maintain conservative loading rates (for wetlands protection) and allow resting or drying periods is desirable. Proposed sizing guidelines of 1) sixty people per hectare (2.47 acres) (for 50 percent nutrient removal) (Nichols 1983) or 2) one inch per week can be used as preliminary indicators (Odum 1976). Larger loading rates, requiring less area are appropriate under some circumstances. More detailed analyses are necessary, however, to determine the amount of wetland area required for achieving proper assimilation and meeting standards. An important consideration in estimating size is the "effective" size of the wetland. Since total mixing may not occur in a wetland due to hydraulic gradients and loadings, the portion of the wetland involved in renovation or impacted by the discharge should be evaluated. How this relates to design decisions is discussed in greater detail in Chapter 6. General guidelines considered for preliminary screening are discussed in the User's Guide.

The topography of a wetland also should be considered as it pertains to wastewater management objectives. If disposal/assimilation is the major objective, then the topography of the wetland primarily will affect engineering planning (e.g., determination of discharge mechanism as it controls distribution and velocity). Wetland topography also affects certain uses. A wetland with irregular boundaries would enhance wildlife habitat values, while a wetland with contrasting relief might increase recreational potential. If enhanced wastewater renovation is the main objective then the topography of the wetland also could affect the feasibility assessment. In this case the shape, slope, channelization pattern and bottom surface need to be assessed since they affect the stated objective (e.g., nutrient removal, sediment trapping). Adamus and Stockwell (1983) provide some discussion of the relationship of wetland topography to wetland processes and values. Impacts of wetland size and topography on engineering design are discussed further in Chapter 6.

Listed below are some of the major limitations to wetlands use which could be encountered in assessing wetland size. Potential mitigation options also are listed.

Wetland Size and Topography -
Major Limitations to Wetland Use

Limitation	Potential Mitigation
1. Area not sufficient for flows of one inch/week.	o Consider multiple cells or adjacent wetland that would allow for resting of wetland. o Use wetland to treat only part of the wastewater flow. o Demonstrate that greater flows will maintain wetland standards and prevent degradation.
2. Size requirements uncertain due to lack of available information.	o Conduct pilot study, if feasible. o Propose increased monitoring and backup system.
3. Effective size difficult to determine.	o Propose additional monitoring to establish area of influence. o Conduct pilot study, including tracer analysis.
4. Topography unsuitable for wastewater management objectives.	o Locate another wetland. o Modify objectives. o Propose additional treatment/engineering practices.
5. Effects of topography uncertain.	o Conduct pilot study. o Reassess objectives.

Wetland Availability and Access. A proposed wetland site may meet other requirements; but if availability and access are constraining, the project may not be feasible. Availability refers in part to the ownership of the wetland. Many wetlands, particularly hydrologically isolated systems such as Carolina Bays or cypress domes, often are owned privately. If the wetlands being considered are waters of the U.S. and are owned privately, are they available through purchase, land trade or long-term lease? Access or control of privately held wetlands must be demonstrated in most states for wastewater management use.

If the wetland is owned publicly, availability is less of a problem if the potential discharger is a public utility. Availability of a publicly owned wetland as a discharge site for a private discharge may require mechanisms similar to those discussed for privately held wetlands.

Access to a wetland has two components: access from the treatment facility and access to the wetland. The major cost associated with using wetlands for wastewater management is typically that of conveying effluent to the wetland. Therefore, the distance of the wetland from the treatment facility is important. If the wetland is too far from the treatment facility, the wetland alternative may prove to be too expensive because of pumping costs. In the case where adjacent wetlands are required to have sufficient wetland acreage, one wetland may be close, whereas the second system may be too distant to be cost-effective. These issues are discussed further in Chapter 6.

The other aspect of access relates to access to the wetland itself. From a public health standpoint, will access by the public to the wetland be controlled if used for wastewater management? In cases of smaller, isolated wetlands, this may be possible. For interconnected systems, this may be impractical. Also, for operational and monitoring purposes, is the wetland easily reached, or will special vehicles be necessary for access under some conditions?

Additionally, a wetland should have ease of access for construction, monitoring and maintenance. Distance, underbrush, wet soils and lack of stream channels can limit access under certain conditions. Such limitations need to be considered in evaluating a potential wetlands site.

Listed below are some of the major limitations to wetlands use which could be encountered in assessing wetland availability and access. Potential mitigation options also are listed.

Wetland Availability and Access -
Major Limitations to Wetland Use

Limitations	Potential Mitigation
1. Privately owned wetland not for sale.	o Long-term lease, land swap, easement with use rights.
2. Publicly owned wetland has other uses.	o Design discharge to minimize effects to other uses. If not possible, wetland is not appropriate for use.
3. Access to a wetland receiving wastewater cannot be controlled.	o Work with public health department to provide adequate safeguards.
4. State requires ownership for adequate control of site, but ownership is not possible nor affordable.	o Check legal options (e.g., condemnation). If not appropriate, evaluate another site or pursue other options.
5. Access to wetland is difficult during wet periods.	o If affordable, purchase equipment necessary.

Environmental Condition and Sensitivity. At the preliminary screening stage, a detailed analysis of environmental conditions including vegetation, macroinvertebrates, water quality, water budget and seasonal characteristics is not necessary. At this stage, however, the general environmental condition and sensitivity of the proposed wetland site should be examined. This can be accomplished primarily from maps and a field visit.

The environmental condition of a wetland refers to its current state and functions. Primary considerations are other pollutant sources to the wetland, visible signs of stress to vegetation, changed use patterns and hydrologic interconnections. A general consensus exists among most wetland scientists that using wetlands which already have experienced some modifications or influences from development would be preferential to using a wetland in its pristine state. In other words, in searching for wetlands discharge sites, systems that have some prior modification should be evaluated first. A higher degree of protection should be afforded those wetlands that are in or near pristine condition. Land use maps often can assist in defining existing or projected development affecting wetlands.

Environmental sensitivity is an equally important element in assessing the long-term ability of a wetland to receive wastewater, yet maintain its functions and values. Table 8-3 indicates the general sensitivity of certain wetland types to perturbations. Some wetlands in their natural state are more vulnerable to changes in water levels or water chemistry than others. Potential changes in hydroperiod resulting from a wastewater discharge is probably the most important consideration. Also, little is known about the sensitivity of some wetlands types that have not been studied extensively. A higher level of protection should be afforded these systems (e.g., Atlantic White Cedar bogs, Carolina bays). Environmental sensitivity needs to be considered on a site-specific basis for many of the reasons discussed above. Wetlands having experienced modifications need to be examined for stress to assess additional impacts from discharging wastewater. Table 2-3 provides information on unique and endangered wetland types.

It is widely accepted that changes will occur in a wetland receiving wastewater. The key consideration is whether the wetland can remain viable after initiating hydrologic or chemical modifications. The importance of wetland changes resulting from wastewater discharges further depends on the extent of change that is considered acceptable.

Listed below are some of the major limitations to wetlands use which could be encountered in assessing environmental condition and sensitivity. Potential mitigation options also are listed. The suggested mitigation for limitations 1 and 2 actually could serve to reverse wetland stress caused by other activities.

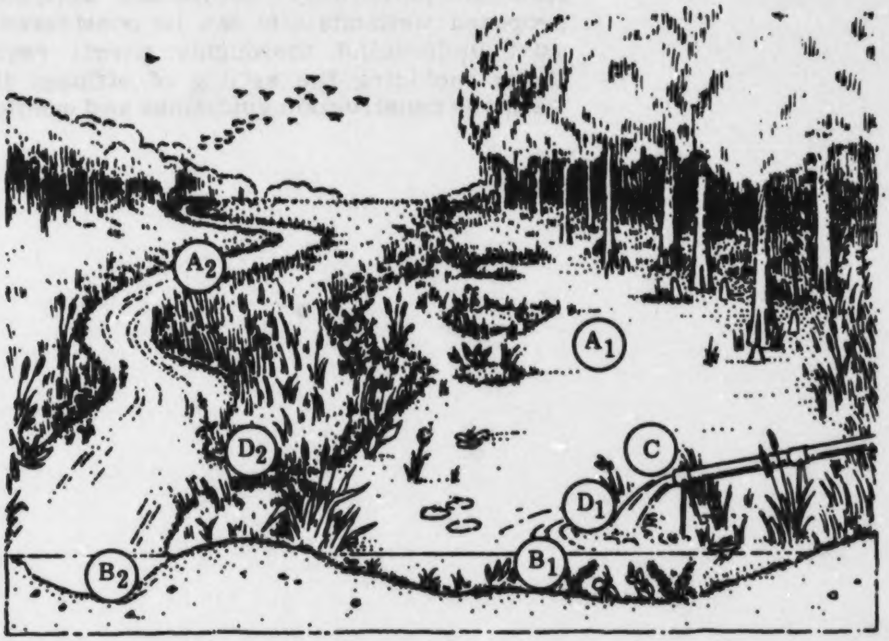
Environmental Condition and Sensitivity - Major Limitations to Wetland Use

Limitations	Potential Mitigation
1. Flows into a wetland have been affected by modifications in the watershed.	o Wastewater flows might actually restore flows that have been diverted.
2. Flows from a wetland have been affected by modifications in the watershed.	o In the case where modifications to the outlet have caused ponding, obstructions may need to be removed.
3. Wetland has been channelized.	o Return spoil to channel, as feasible, to permit normal flooding and flow patterns through the original flood plain.
4. The only wetland available is sensitive to changes in flow.	o If possible, schedule flows to reflect the natural wet and dry seasons. Storage ponds or multiple cells may be necessary.
5. The only wetland available is sensitive to changes in water chemistry.	o If additional treatment steps to minimize the expected changes cannot be provided, the site should be rejected.

Permitting Considerations and Effluent Limitations. In the practical application of assessing the use of wetlands for wastewater management, the preliminary screening phase is the appropriate time for evaluating the permit considerations of the specific project being proposed. Figure 4-3 displays some of these considerations.

Regardless of the applicability of Construction Grants guidelines, permit requirements and conditions always will be applicable to any discharge to wetlands considered waters of the U.S.

Figure 4-3. Potential Permitting Issues Affecting Preliminary Site Screening and Engineering Planning.



Step 1. IDENTIFY PROTECTED USES:

A_1 Wetland use classification or
A_2 Adjacent water body use classification

Step 2. ESTABLISH WATER QUALITY STANDARDS TO MAINTAIN PROTECTED USES:
B_1 Wetland Water Quality
B_2 Downstream Water Quality (if applicable)

Step 3. DETERMINE WASTEWATER DISCHARGE LOADING CRITERIA WITHIN WETLAND TOLERANCE LIMITS.

C Point of Discharge

Step 4. ESTABLISH EFFLUENT LIMITS BASED ON WETLAND WATER QUALITY STANDARDS AND DISCHARGE LOADING CRITERIA.

D_1 Usual Point of Discharge into Wetland

D_2 Leaving the Wetland if Wetland is used for its Assimilative Capacity.

Source: CTA Environmental, Inc. 1985.

Permit considerations potentially could eliminate the use of a particular wetland for wastewater management even if the preliminary screening technical appraisal appears positive. The applicant should work closely with the regulatory agency responsible for permitting. Before the wetlands alternative and the proposed wetlands site can be considered viable, the applicant must understand thoroughly permit requirements and conditions, including the setting of effluent limits, design factors, wetlands construction guidelines and monitoring.

4.3 COMPARISON OF WETLANDS USE TO OTHER ALTERNATIVES

Before efforts are made to gather detailed site evaluation information, the wetlands alternative should be compared and evaluated with other wastewater management systems (e.g., surface water discharge, land application, wastewater reuse, etc.). If the project is being funded by Construction Grants program, the alternative comparision process is included as part of the 201 Facilities Plan. The core method used, and that which meets EPA requirements, is a cost-effectiveness analysis. This type of analysis involves determining and comparing:

- Costs
- Environmental Impacts
- Operational Features
- Implementation Factors.

Information on these factors should be gathered for each alternative to determine if that alternative meets wastewater management needs of the community. The list of viable alternatives can then be analyzed to establish the most cost-effective alternative. The least-cost alternative is not necessarily the most cost-effective alternative.

The first phase of the process is determining project viability. It is obvious that a project is viable only if the benefits derived exceed the project costs. For wetland-wastewater alternatives some costs and benefits include:

Benefits

- Wetlands preservation
- Maintenance of wetland values for flood control, timbering, etc.
- Possible harvested commodities (timber, fish, forage)
- Enhanced wastewater assimilation, improving downstream or adjacent waters.
- Avoiding public health or environmentally damaging problems of other wastewater alternatives
- Possible receipt of grant funding (e.g., I/A funds)
- Relatively low technology system

Costs

- Capital Costs (design, equipment, installation)
- Operation, maintenance & replacement costs (energy, labor, chemicals)
- Land access & legal costs
- Monitoring
- Possible costs to home & business from lowered property values
- Environmental loss in land, air and water systems
  - a) Water quality
  - b) Aquatic habitat
- Possible adverse public reaction

Most of the benefits and certain types of costs cannot be quantified in one numerical value. One of the key aspects of a cost-effectiveness analysis is comparing ranges of values and qualitative descriptions with quantifiable dollar costs. The person analyzing costs and benefits needs to consider carefully why certain benefits and costs cannot be quantified and how quantifiable factors can be equated to qualitative factors. In determining project viability and comparing alternatives, a decision matrix or other method that systematically compares alternatives could be used. These methods allow for subjective information and qualified judgement to enter the decision process.

4.3.1 Cost Analysis

Cost analyses for wetlands-wastewater systems are largely dependent on the thorough identification of wetlands uses and interconnections with other water bodies. The proximity of proposed wetlands sites to the treatment facility and community also is a primary element of a cost analysis. Other engineering options which might affect costs of a wetlands-wastewater system, such as dechlorination or distribution systems, should be assessed as well. Hyde et al. (1982) and Southerland (1985) discuss economic aspects of using wetlands for wastewater management.

Of special interest to wetlands systems is the concern for appraising the wetland resources that are either lost or gained by utilizing the wetland as a wastewater management system. Many wetlands functions and values have a direct cost valuation, such as timber removed from bottomland hardwoods or commercial fish and shellfish harvesting. Other values may be indirectly tied with the wetland under consideration: for example, in many wetlands, fish migration up and down associated streams is important not only to andromous fishes in the lower Coastal Plain, but also to resident freshwater species that move into the headwaters for spawning. Also, wetlands with unused hydraulic storage can act as valuable flood control systems for downstream areas.

A wetland used as a wastewater management system may continue to function in other commercially valuable roles if properly designed and managed, or valuable roles may be lost. The value placed on these roles can be converted to dollars if a harvestable product is involved, an equivalent facility construction cost can be determined or projections of cultural gains or losses can be made (e.g., timbering, flood damage, eutrophication prevention, recreational usage). This evaluation should be conducted for all potential wetlands discharges, with emphasis on Tier 2 discharges. Dollar costs which can be quantified should be determined with traditional engineering cost estimating procedures. Two methods are available for assessing one-time and periodically-occurring costs, allowing for the time lag between planning and construction and equating the cost value of different service lives of equipment and facilities: present worth and equivalent uniform annual costs. These costing methods can be used for comparing wetland-wastewater management systems with other treatment/disposal system alternatives in the same manner as they are applied to other types of wastewater systems. Figure 4-4 displays the type of cost-comparison that is helpful in evaluating alternatives.

4.3.2 Environmental Impacts

Environmental impact evaluations include determining the effects of the proposed systems on natural factors (e.g., water quality and quantity, aquatic and terrestrial ecology, groundwater, geology, air quality) and man-made factors (e.g., public health, recreation and land use). Environmental benefits and disadvantages pertinent to feasibility can be described and assessed qualitatively. Significance, duration, seasonal variation and reversibility of environmental impacts merit evaluation. For some environmental factors, such as surface water quality in relation to treatment requirements, input from state environmental agencies is needed. Measures to mitigate environmental impacts also should be considered.

Potential environmental impacts that should be assessed and compared for wastewater management alternatives which include wetlands are:

- Stress imposed due to wastewater quantity or quality (e.g., hydraulic overloading or industrial constituents)
- Alteration of economic value or land use near selected site and/or surrounding upland area due to wastewater input
- Possible channelized flow through the wetland downstream of the discharge
- Possible generation of odors and propagation of disease-transmitting organisms
- Potential production of chlorinated hydrocarbons associated with some wetland soils
- Changes in vegetation species, productivity or diversity
- Impacts to wildlife or their habitat
- Impacts on sensitive or unique wetlands
- Impacts to downstream water quality and uses.

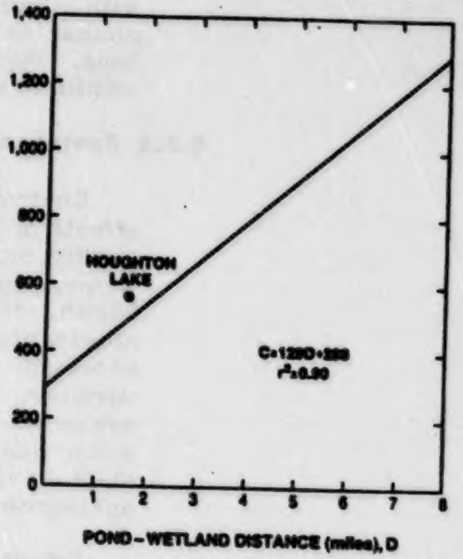
A valid alternatives comparison requires assessing the impacts of all potential alternatives. Land application, stream discharges and small community systems all have potential benefits, as well as potential adverse environmental impacts. The size of the discharge, the amount of land or streamflow, existing environmental conditions, sensitivity to wastewater flow, assimilative capacity, public health concerns and ecological

Figure 4-4. Examples of Cost Comparisons Using Wetlands for Wastewater Management.

Wetland Costs

vs

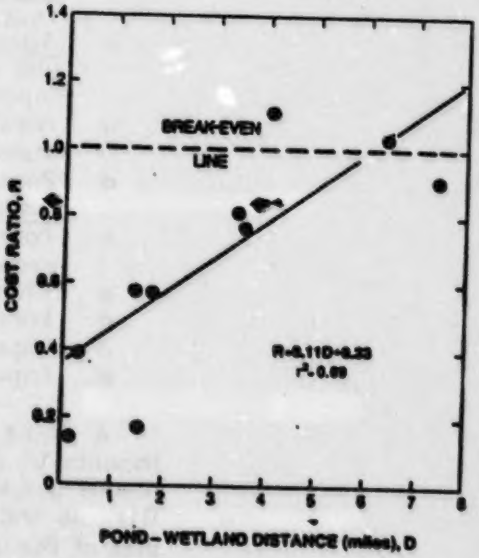
Distance from Ponds



Wetland: Spray Irrigation Cost Raio

vs

Wetland Distance



Source: Southerland 1985.

characteristics should be evaluated for each alternative. A discussion of potential wetlands responses to wastewater application is presented in Chapter 8.

4.3.3 Operational Features

Operational features for wastewater management alternatives include reliability of system performance to maintain effluent limitations and permit requirements (e.g., biological monitoring, instream performance criteria, post-discharge monitoring), maintenance needs (e.g., energy requirements, variable climate conditions, vegetation maintenance or harvesting) and flexibility in operating the wastewater system (e.g., controlling flows to wetlands, variable discharge schedules, seasonal operation). As with environmental effects, operational factors are not easily quantifiable, but they can be described qualitatively. Operation features and options for wetlands discharges are discussed in Chapter 7.

4.3.4 Implementation Factors

Implementation determinants include the ability of a municipality to pay for a proposed project (user charges, wetland purchase if required), public acceptance as measured throughout the facilities planning/EIS process, possible institutional constraints (such as zoning, land ownership or existing municipal debt) and planning flexibility (e.g., space for treatment plant expansion, multiple wetlands cells for resting periods).

Wetland-wastewater systems may find diverse and confusing public acceptance. Many people view wetlands as valuable and highly sensitive systems; others consider wetlands as nuisance areas that breed mosquitoes. People with these attitudes could resist wastewater application in wetlands, expecting it to worsen existing conditions (more mosquitoes) or to worsen the already damaged or limited ecosystem. Public education based on increasing knowledge of wetlands used for wastewater management and experience with impact-reducing engineering options may be a necessary aspect of wetlands-wastewater system implementation. Uncertainties and risks still associated with wastewater discharges also would need to be addressed in conjunction with potential mitigation alternatives.

4.4 DETAILED SITE EVALUATION

If the use of wetlands as part of a wastewater management plan still is feasible after preliminary site screening and comparison with other alternatives, the detailed site evaluation should be conducted. This evaluation builds on information gained from the previous tasks and serves the following functions:

1. It is the primary scientific determination of wetlands site feasibility
2. It is the basis for engineering design
3. It provides background information for assessing wetlands impacts.

This section highlights the major scientific and cultural aspects of wetlands critical to understanding and assessing wetlands use fully, which provides the basis for decision making and engineering design. After this evaluation, the primary institutional and scientific issues should have been addressed, leaving engineering design considerations as the final step for determining wetlands site feasibility. The scope of work for the detailed site evaluation will be determined on a project specific basis. It will depend on elements such as wastewater loading, wetland type, wetlands processes and uses, wetland sensitivity, etc. Differences in the scope of evaluations for wetland discharges are suggested in Section 3.3.4, based on the concept of tiering information requests depending on the relative uncertainties associated with the proposed discharge. Generally, if a wetland discharge incorporates conservative features (i.e., low loading rates, small volume, altered wetland, disposal only) less information would be required. Discharges presenting greater risk or uncertainty would be asked to provide more information. The impact of a tiering system for information requests depends on whether a state adopts such a system, the criteria on which it is based and associated guidance. Section 9.2 provides information on how to perform the evaluations discussed.

4.4.1 Considerations and Current Practices

Most Region IV states conduct site investigations for wetlands proposed for wastewater management use. These analyses typically include an assessment of the visual condition of the wetland, potential pollutant sources, existing uses and general hydrologic characteristics. Procedures for conducting site investigations typically are not well-defined. From a regulatory perspective, the detailed site evaluation could serve to provide needed information concerning site-specific standards and effluent limitations. Therefore, it is recommended that the scope and detail of site investigations be considered in light of these potential regulatory needs. The applicant and regulatory agency should work closely when designing the detailed site evaluation to assure that the needs of both are met. Information for permit applications which leads to permit conditions could be obtained from the detailed site evaluation or state-conducted on-site assessments.

4.4.2 Evaluation Components

Seven components of a detailed site evaluation are discussed below. These components represent the range of information necessary to assess fully a potential wetlands discharge site, including:

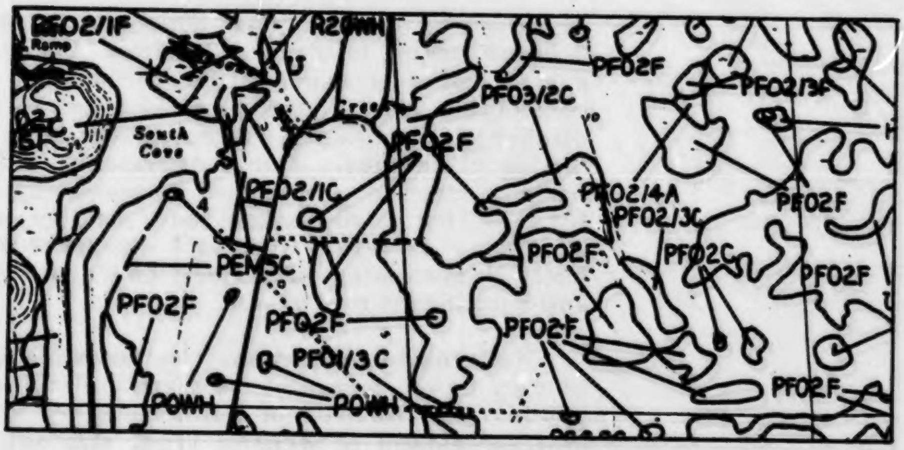
1. Wetlands identification
2. Wetlands values and uses
3. Watershed characteristics and connections
4. Water budget and hydroperiod
5. Background water quality conditions
6. Wetland ecology
7. Soils characteristics.

The need to evaluate these components and their importance to decision making is discussed below. Using the proposed tiering system, some elements of the components presented would be considered Tier 1 discharge assessments and others Tier 2 discharge assessments. Tier 1 assessments would be conducted for all discharges. Tier 2 assessments will be categorized as basic or elective. Basic Tier 2 assessments would be conducted for all Tier 2 discharges and elective assessments only as conditions warrant. Chapter 9 discusses the different levels of analyses associated with Tier 1 and Tier 2 information requests, and appropriate methods.

Wetlands Identification. Wetlands identification is composed of two major elements: wetlands classification and wetlands boundaries. As part of the preliminary site screening, a general assessment of wetland type, size and topography is conducted. This evaluation should confirm the wetland classification and boundaries as a basis for assessing wetlands functions and values and to meeting regulatory requirements. Ultimately, engineering design will be based on characteristics associated with specific wetland types.

The U.S. Fish and Wildlife Service (FWS) method for classifying wetlands generally is regarded as the most thorough and accurate method. The distinction should be understood, however, between wetlands defined by Clean Water Act regulations and the classification of wetland type. The former defines wetlands that are waters of the U.S., the latter classifies the type of wetland. Through the National Wetlands Inventory, many wetlands within Region IV states have been mapped. If maps have not been developed for a particular area, the field offices of the FWS can be contacted for assistance in classifying a wetland. Figure 4-5 provides an example of a National Wetlands Inventory map and its potential use for identifying wetland types and boundaries. Methods that have been used on a local or state-wide basis offer another means for assessing wetland type and boundaries. Table 2-1 shows the relationship between common names for wetlands types and the FWS counterpart. From a regulatory viewpoint, it is helpful to identify a wetland by both descriptors. Wetland types respond in a variety of ways to wastewater additions. In some wetlands the hydraulic loads will be most important; in others the potential changes in water chemistry will be critical. The timing or scheduling of discharges also will be more crucial in some wetlands than others. Table 8-3 presents some known sensitivities of different wetland types.

Figure 4-5. National Wetlands Inventory Map for an Area near Clearwater, Florida.


R20WH
Romo
South Cove
Creek
PF02F
PF03/2C
PF02/3F
PF02F
PF02/1C
PF02/4A
PF02/3C
PF02F
PEM5C
PF02F
PF02C
PF02F
PF02F
PF02F
PF01/3C
PF02F
POWH
POWH
PF02F

Example Legend: National Wetlands Inventory, Oldsmar, FL.

PEM5C -	Palustrine, emergent, narrow-leaved, persistent, seasonal water regime
PF02F -	Palustrine, forested, needle-leaved deciduous, semipermanent water regime
POWH -	Palustrine, open water, permanent water regime

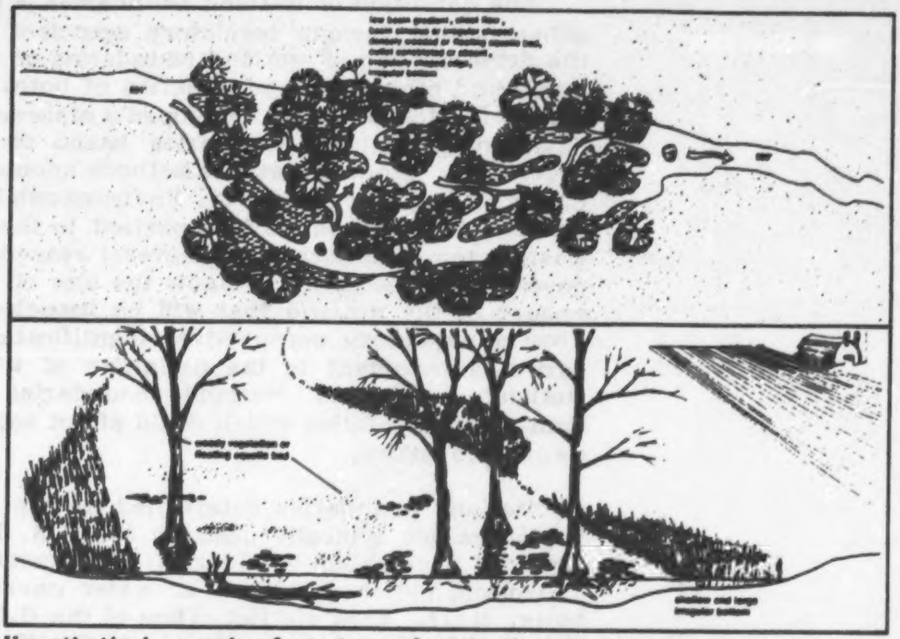
The definition of wetland boundaries is a topic of continuing debate among various regulatory agencies. Some agencies base the determination of wetland boundaries on soils, some on vegetation and others on a combination of both. Florida is the only Region IV state that has developed a state-authorized system for determining wetland boundaries based on a list of wetlands vegetation. Other states use methods adopted by the U.S. Army Corps of Engineers and U.S. Environmental Protection Agency. The issue of boundaries is important to the use of wetlands for wastewater management for several reasons. For design purposes, it is necessary to know the size of the wetland and the amount of the wetland that will be impacted by the discharge. From a regulatory perspective, identification of wetland boundaries is important to the definition of what is, or is not, a wetlands discharge. Wetlands boundaries determine jurisdictional responsibilities which could affect access, availability and ownership issues.

Wetland boundaries determined by the U.S. Army Corps of Engineers are typically used by the U.S. EPA. Three criteria are used to establish boundaries: 1) vegetation, 2) soils, and 3) hydrologic indicators (such as water marks on trees, crayfish holes, etc.). Each district office of the U.S. COE has a vegetation list developed for wetlands under their jurisdiction. For waters defined as waters of the U.S., the National Wetlands Inventory might also be used to assess wetland boundaries in conjunction with topographic and soils maps and aerial photographs.

Wetlands Values and Uses. It is important to identify the major values and uses of any wetland being considered for wastewater management. If the wetland area is addressed adequately by the WQS program, its major uses and use potential should be identified. States' antidegradation policies relating to existing uses may also affect wastewater management decisions.

Assessments should be made on a site-specific basis to estimate the degree to which the primary wetland functions and values listed in Table 2-2 will be impacted by a wastewater discharge. Table 4-1 summarizes the relationship between various wetland characteristics and wetland functions. Such relationships should be evaluated in the decision-making process. Multiple uses also should be recognized and, if necessary, addressed by the design and mitigation planning processes. A potential wetlands discharger should contact the appropriate regulatory agencies prior to developing a sampling program to determine which parameters will be required by regulatory guidelines (i.e., either incorporated into the WQS program or NPDES permit conditions). Also, it should be determined whether the state or applicant is responsible for evaluating certain parameters. Figures 4-6, 4-7 and 4-8 display how different wetland characteristics can affect wetland values and uses.

Figure 4-6. Values and Uses Associated with Different Wetland Characteristics.



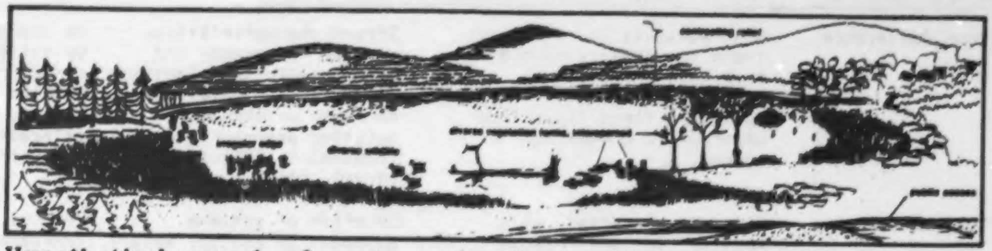
Hypothetical example of one type of wetland whose probability of being effective for nutrient retention and removal might be high.

Source: Adapted from Adamus and Stockwell 1983.

Watershed Characteristics and Connections. The presence or absence of hydrologic interconnections between a wetland and surface or ground waters is important to the consideration of using wetlands for wastewater management regardless of tiering. Most wetlands are hydrologically connected; i.e., they have a direct connection to or from surface waters. Some wetlands, e.g., cypress domes, are isolated with no connections to surface waters. A topographic map, as shown in Figure 4-9, or aerial photography often can be used in this assessment.

Hydrologic interconnections, or the lack thereof, influence assimilative capacity, residence time in the wetland and nutrient/materials transport. Wastewater flows to a hydrologically open wetland will impact downstream aquatic systems. Storm events can cause flushing of a wetland, reducing residence time and, ultimately, assimilative capacity. If the wetland is being used to polish wastewater, the potential for "short-circuiting" normal wetlands processes must be incorporated into decision making. If the wetland is not being used for polishing, but merely disposal, this is of less concern. Regardless, the impacts of hydrologically-connected wetlands systems to downstream waters and their designated uses needs to be addressed by the permitting process.

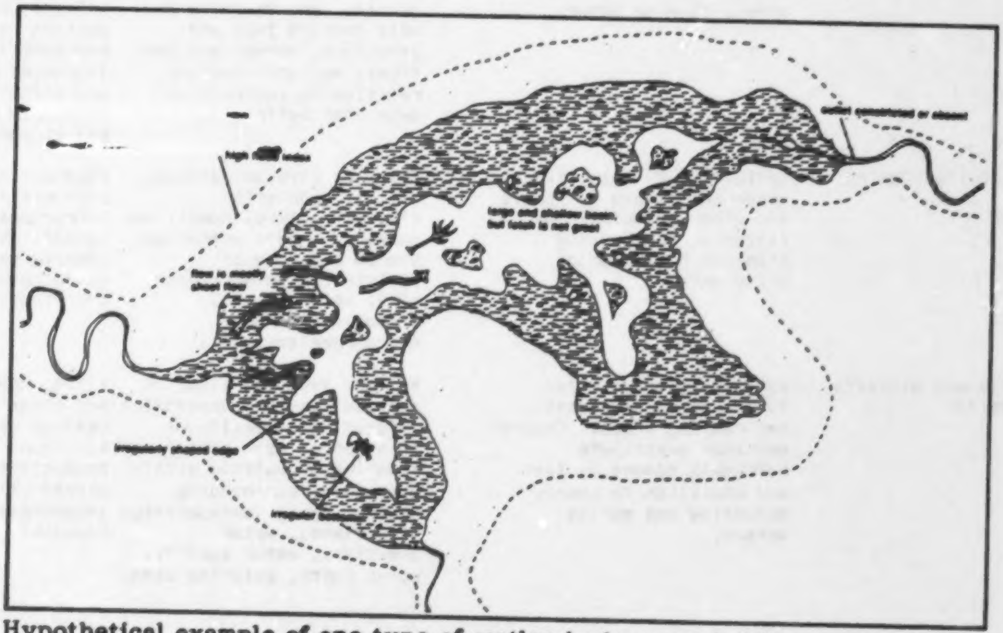
Figure 4-7. Values and Uses Associated with Different Wetland Characteristics.



Hypothetical example of one type of wetland whose probability of providing good opportunities for passive recreation might be high.

Source: Adapted from Adamus and Stockwell 1983.

Figure 4-8. Values and Uses Associated with Different Wetland Characteristics.


outlet constricted or absent
large and shallow basin, but fetch is not great
flow is mostly sheet flow
irregularly shaped edge
irregular bottom

Hypothetical example of one type of wetland whose probability of being effective for sediment trapping might be high.

Source: Adapted from Adamus and Stockwell 1983.

Table 4-1. Features Affecting Wetlands Values and Uses.

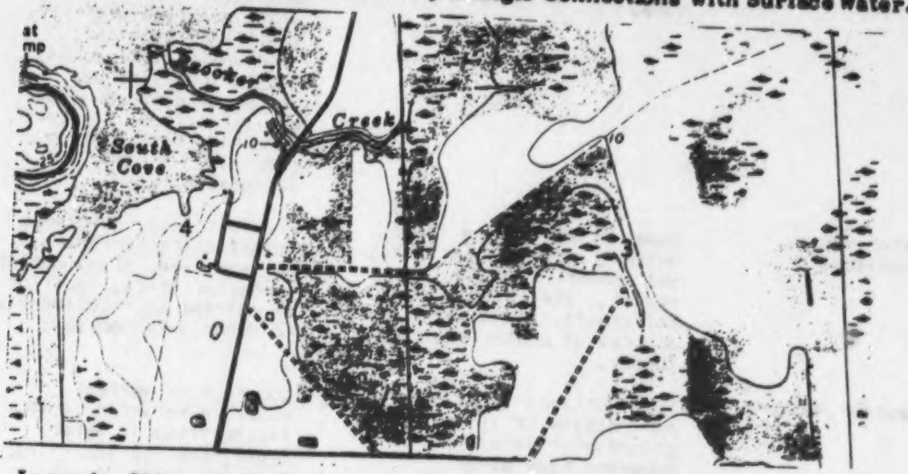
Wetland Function	How Wetlands Perform Function	Factors Determining Importance of Function	Concern
Flood Conveyance	Some wetlands (particularly those immediately adjacent to rivers and streams) serve as floodway areas by conveying flood flows from upstream to downstream points.	Stream characteristics, wetland topography and size, vegetation, location of wetland in relationship to river or stream, existing encroachment on flood-plain (dikes, dams, levees, etc.).	If flood flows are blocked by fills, dikes or other structures, increased flood heights and velocities result, causing damage to adjacent, upstream and down-stream areas.
Wave Barriers	Wetland vegetation, with massive root and rhizome systems, bind and protect soil. Vegetation also acts as wave barriers.	Location of wetland adjacent to coastal waters, lakes, and rivers, wave intensity, type of vegetation, and soil type.	Removal of vegetation increases erosion and reduces capacity to moderate wave intensity.
Flood Storage	Some wetlands store and slowly release flood waters.	Wetland area relative to watershed, wetland position within watershed, surrounding topography, soil infiltration capacity in watershed, wetland size and depth, stream size and characteristics, outlets (size, depth), vegetation type, substrate type.	Fill or dredging of wetlands reduces their flood storage capacity.
Sediment Control	Wetland vegetation binds soil particles and retards the movement of sediment in slowly flowing water.	Depth and extent of wetland, wetland vegetation (including type, condition density, growth patterns), soil texture type and structure, normal and peak flows, wetland location relative to sediment of vegetated buffer.	Destruction of wetlnad topographic contours or vegetation decreases wetland capacity to filter surface runoff and act as sediment traps. This increases water turbidity and siltation of downstrea reservoirs, storm drains, and stream channels.
Pollution Control	Wetlands act as settling ponds and remove nutrients and other pollutants by filtering and causing chemical breakdown of pollutants.	Type and size of wetland, wetland vegetation (including type, condition, density, growth patterns), source and type of pollutants, water course, size, water volume, streamflow rate, microorganisms, etc.	Destruction of wetland contours or vegetation decrerases natural pollution capability, resulting in lowered water quality for downstream lakes, streams and other waters.
Fish and Wildlife Habitat	Wetlands provide water, food supply, and nesting and resting areas. Coastal wetlands contribute nutrients needed by fish and shellfish to nearby estuarine and marine waters.	Wetland type and size, dominant wetland vegetation (including diversity of life form), edge effect, location of wetland within watershed, surrounding habitat type, juxtaposition of wetlands, water chemsitry, water quality, water depth, existing uses.	Fills, dredging, damming, and other alterations destroy and damage flora and fauna and decrease productivity. Dam construction is an impediment to fish movement.

Table 4-1. Continued.

Wetland Function	How Wetlands Perform Function	Factors Determining Importance of Function	Concern
Recreation (water-based)	Wetlands provide wildlife and water for recreational uses.	Wetland vegetation, wildlife, water quality, accessibility to users, size, relative scarcity, facilities provided, surrounding land forms, vegetation, land use, degree of distrubance, availability of similar wetlands, distribution, proximity of uses, vulnerability.	Fill, dredging or other interface with wetlands will cause loss of area for boating, swimming, bird watching, hunting and fishing.
Water Supply (surface)	Some wetlands store flood waters, reducing the timing and amount of surface runoff. They also filter pollutants. Some serve as sources of domestic water supply.	Precipitation, watershed runoff characteristics, wetland type, size, outlet characteristics, location of wetland in relationship to other water bodies.	Fills or dredging cause accelerated runoff and increase pollution.
Aquifer Recharge	Some wetlands store water and release it slowly to groundwater deposits. However, many other wetlands are discharge areas for a portion or all of the year.	Location of wetland relative to water table, fluctuations in water table, geology including type and depth of substrate, permeability of substrate, size of wetland, depth. Aquifer storage capacity, groundwater flow, runoff retention measures.	Fills or drainage may destroy wetland aquifer recharge capability, thereby reducing base flows to streams and groundwater supplies for domestic, commercial or other uses

Source: Adapted from Henderson et al. 1983.

Figure 4-9. Use of Topographic Map to Evaluate Watershed Characteristics and Hydrologic Connections with Surface Water.



Legend: Oldsmar, FL Quad
Contour interval - 5 feet
—··· —··· - intermittent flow

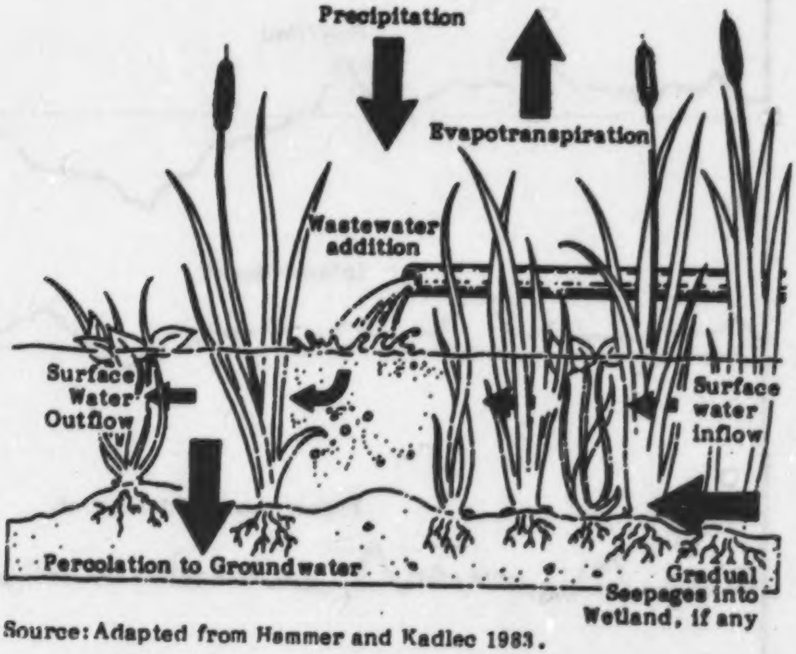
Hydrologically isolated wetlands present a different type of concern. Flushing in such systems is dependent wholly on evapotranspiration, rainfall and groundwater interactions; overloading the system with excessive flows or pollutants is a higher risk than for most open systems. Groundwater recharge may be more likely and should be considered in perched, isolated systems. Estimation of discharge rates and the area of wetland needed must be given added attention.

Measuring groundwater interactions with either type of system is typically a difficult task. Few wetlands have direct connections with deep aquifers used for drinking water supplies. Some wetlands, however, are located in recharge or karstic zones and could have an impact on groundwater quality. This should be evaluated in selecting a wetlands site. Examining topographic maps, aerial photography and substrate maps usually provides the level of information needed. Sometimes tracer techniques are useful for following the flow of water through a wetland.

As is evident, hydrologic and watershed characteristics affect engineering design, discharge loading rates, estimation of impacts on downstream uses, wetlands protection and the permitting process.

Water Budget and Hydroperiod. Assessing a wetland's water budget is an important element of detailed site screening. A water budget is basically an accounting of the inflows to and outflows from a wetland as indicated in Figure 4-10. Such information may be needed for engineering planning to determine when and how much water a given wetland might be able to accept without severe stress.

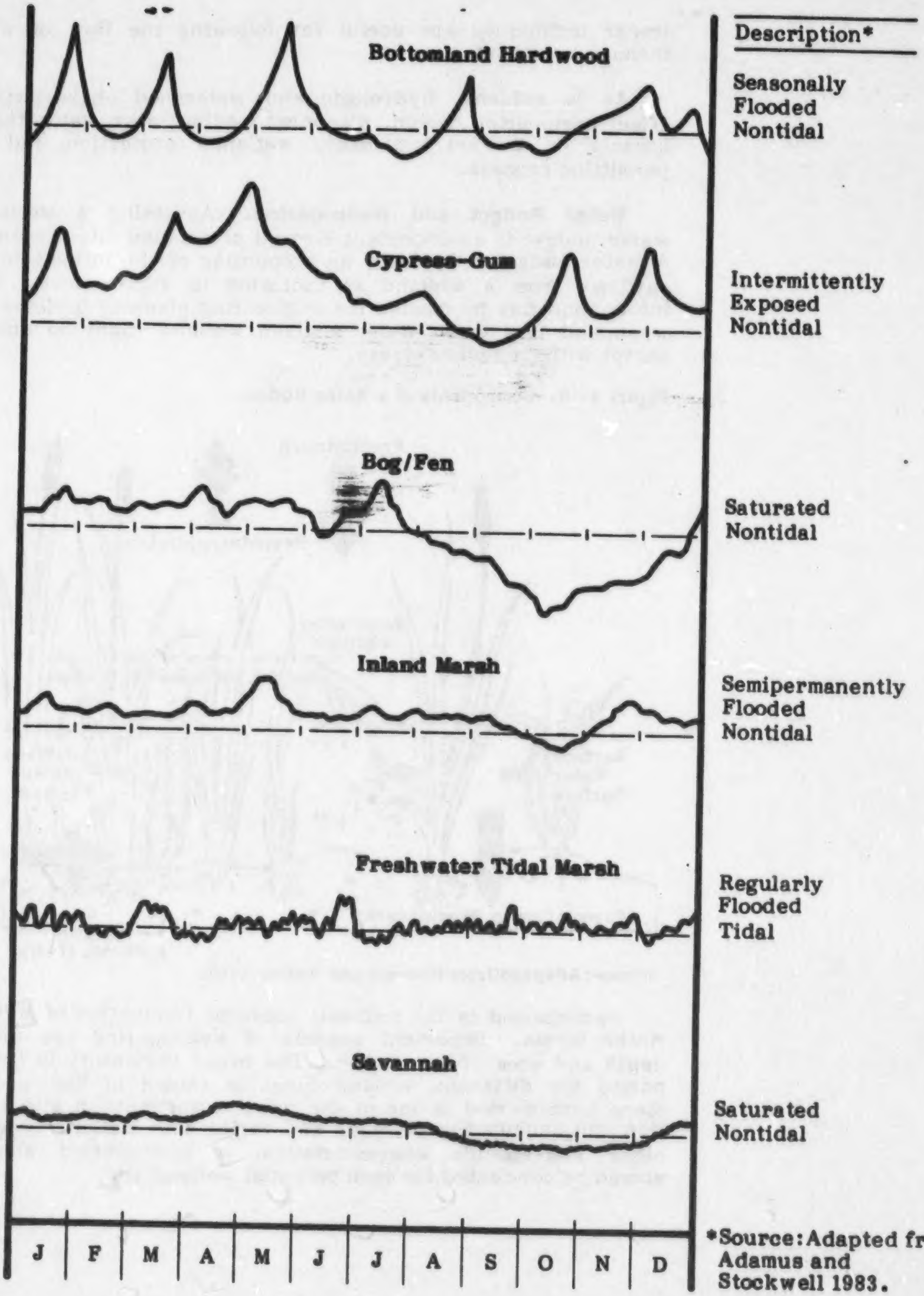
Figure 4-10. Components of a Water Budget.


Precipitation
Evapotranspiration
Wastewater addition
Surface Water Outflow
Surface water inflow
Percolation to Groundwater
Gradual Seepages into Wetland, if any

Source: Adapted from Hammer and Kadlec 1983.

Hydroperiod is the natural, seasonal fluctuation of wetland water levels. Important aspects of hydroperiod are timing, depth and area of inundation. The broad variability in hydroperiod for different wetland types is shown in Figure 4-11. Since hydroperiod is one of the major components of site selection and engineering planning and varies with wetland type and other site-specific characteristics, a hydroperiod analysis should be conducted for each potential wetland site.

Figure 4-11. Typical Hydroperiods of Six Southeastern Wetland Types.



*Source: Adapted from Adamus and Stockwell 1983.

The water budget equation may be written as:

$$\Delta S_t = P + Q_1 + Q_L + G_1 + W - Q_2 - G_2 - E$$

where:

ΔS_t = volume change of water stored in the wetland during a specified time interval, t
P = precipitation volume falling on the wetland during t
Q_1 = surface water volume flowing into the wetland at its upstream end during t
Q_L = Lateral overland flow volume flowing into the wetland during t
G_1 = groundwater volume flowing into the wetland during t
W = wastewater volume applied to the wetland during t
Q_2 = surface water volume flowing out of the wetland at its downstream end during t
G_2 = groundwater volume flowing out of the wetland during t
E = evapotranspiration volume leaving the wetland during t

By calculating the water budget, the major hydrologic interconnections and source of inflow become clear, and residence time can be calculated. For hydrologically open or connected wetlands, estimations of depth, velocity, area of inundation and residence time may be made using a derivation of Manning's equation. Section 9.5 (Hydrologic and Hydraulic Analyses) discusses the water budget and Manning's equation analyses, data requirements and the application of these methodologies to various wetland situations. Suggestions for assessing a wetland's hydroperiod are included in this chapter's User's Guide.

Background Water Quality Conditions. The assessment of background water quality conditions provides information for both the regulatory process (site-specific criteria, permit conditions, monitoring) and engineering design (assimilative capacity, acceptable loading rates). Further, determination of background water quality provides the benchmark against which impacts and future changes can be compared.

It is important to assess the distinction, if applicable, between ambient water quality and natural, background conditions. This involves determining, to the extent possible, if ambient water quality conditions represent natural conditions or modifications caused by other pollutant sources. If other point or nonpoint flows have entered the wetland, the background conditions documented may not be the natural conditions. This may indicate a lower capacity to assimilate wastewater additions. It also may lead to a better determination of wastewater impacts to the wetland and indications of stress.

It is also necessary to make the distinction in water quality between low water and high water conditions. In other words, a hydrologic assessment must be coordinated with the water quality assessment. Has the wetland recently been impacted by storm event runoff? When was the last precipitation event? It is of value to know if the water quality assessment reflects conditions typical of a low flow or non-storm event flow, or a high flow resulting from stormwater. Water quality characteristics vary considerably with different flows. Seasonal influences also impact water quality conditions.

Based on the tiering approach to optimize the water quality information collected, standard analyses have been divided into Tier 1 and Tier 2. Tier 1 constituents are those that should be assessed as part of any background water quality analysis. These analyses are targeted primarily for those situations in which a small discharge is anticipated for a relatively large, hydrologically open wetland system, where the effluent is composed entirely of domestic effluent. Where a discharge is planned for a hydrologically isolated system, or a relatively large flow will be discharged into a small "affected wetland area," or an industrial wastewater component is present, certain Tier 2 constituents should be analyzed as well. All Tier 2 constituents are elective since the specific constituents chosen for analysis will depend on the characteristics of the effluent, wetland, established wastewater management objectives (e.g., nutrient removal) or downstream waters.

Potential Tier 1 constituents include:

- Dissolved oxygen
- pH
- Suspended solids
- Nitrate
- Ammonia
- BOD
- Water temperature
- Fecal coliforms
- Orthophosphate

Potential Tier 2 constituents include:

- Total nitrogen (nutrient removal, nutrient budget, downstream waters)
- Total phosphorus (nutrient removal, nutrient budget, downstream waters)
- Metals (zinc, mercury, lead, iron, copper) (Industrial component, toxicity, bioaccumulation)
- Priority pollutants (Industrial component, agricultural runoff component)
- Total coliforms (public health, disease vectors)
- Fecal Streptococci (bacterial source assessment)
- Un-ionized ammonia (fish toxicity)
- Sulphur (nutrient cycling, bacterial population)
- Chloride (tracer)

Many elective constituents relate to integrative analyses such as nutrient budgets, assimilative capacity, potential water movement through the soil profile, etc.

Wetland Ecology. The determination of predominant wetland vegetation helps classify a wetland. The mix of vegetation also affects habitat and the type of wildlife that will be found in the wetland. Further, the condition and type of vegetation provides a good indicator of assimilative capacity and changes in a wetland. Each of these characteristics of wetlands vegetation is described in greater detail in the Phase I, Freshwater Wetlands for Wastewater Management Report (EPA 1983).

Wetlands vegetation is composed of trees and aquatic vegetation. The latter can be divided primarily into the following three categories: emergent, floating and submergent. Figure 4-12 identifies these three major vegetation types. All three forms play an important role in slowing the flow of water through a wetland, leading to settling of suspended sediments and organic matter, nutrient uptake and oxygen exchange. Vegetation also acts as media for microorganism growth for the breakdown of nutrients and organics.

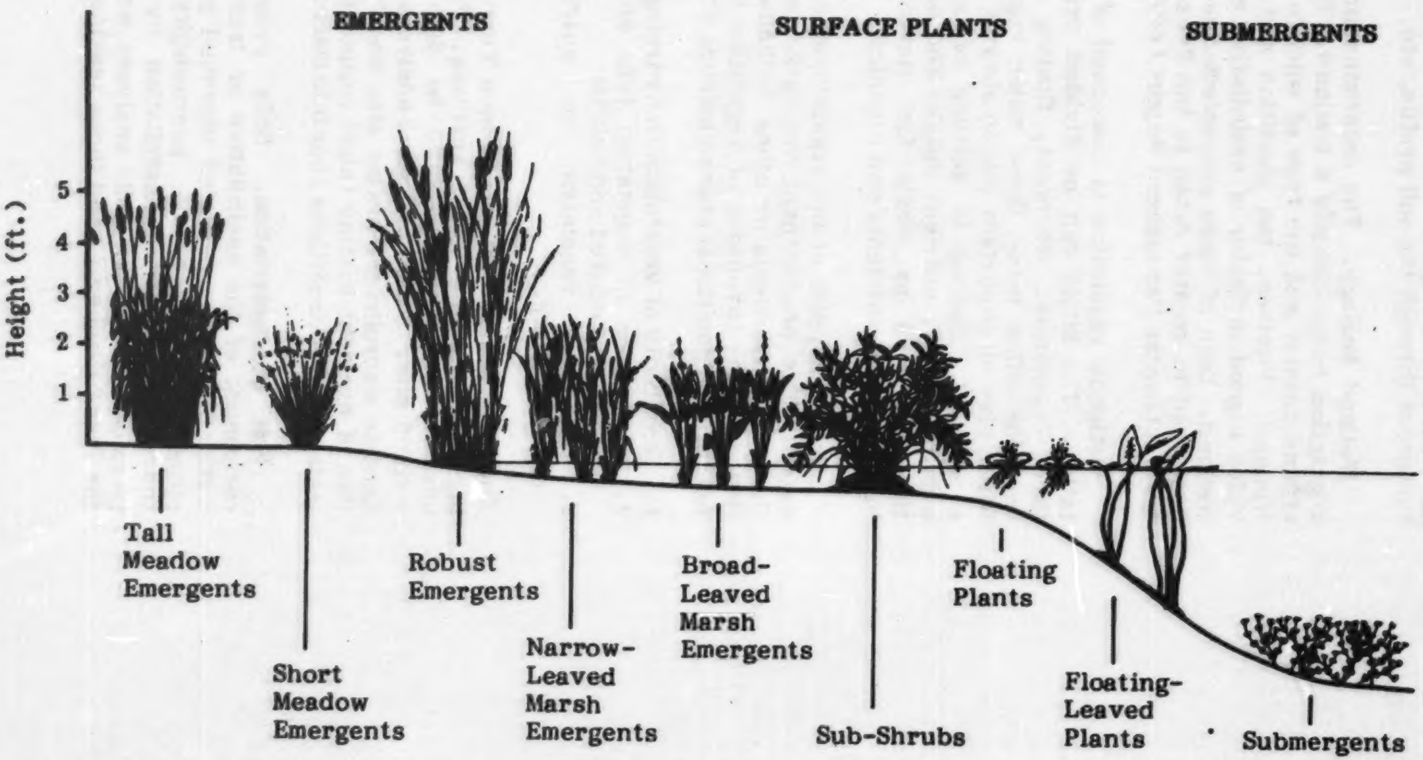
Several aspects of the vegetational assemblage should be evaluated. The predominant vegetation can be identified through the use of transects or other methods described in Chapter 9. Based on the inventory of vegetation type and distribution, the following vegetational characteristics should be evaluated.

1. Sensitivity of vegetation to hydrologic or chemical alterations
2. Correlation of vegetation type and percent open water to breeding potential and habitat
3. Effect of vegetation on nutrient uptake rates and productivity.

The first assessment would be a Tier 1 analysis and the following two would be Tier 2 analyses. Predominant vegetation, or species composition, should be determined for any potential wetand site. Other biological analyses such as chlorophyll a and benthic macroinvertebrates also may be beneficial as an indication of nutrient loading (algal composition and productivity) and water quality conditions (benthic macroinvertebrates).

Soil characteristics. Soils processes are an important component of the assimilative or treatment characteristics of a wetland due to associated microbial processes, exchange capacities and effects on permeability. Soils characteristics, therefore, influence assimilation by biological, chemical and physical processes. Soils analyses would be required primarily for Tier 2 discharges and those seeking nutrient removal.

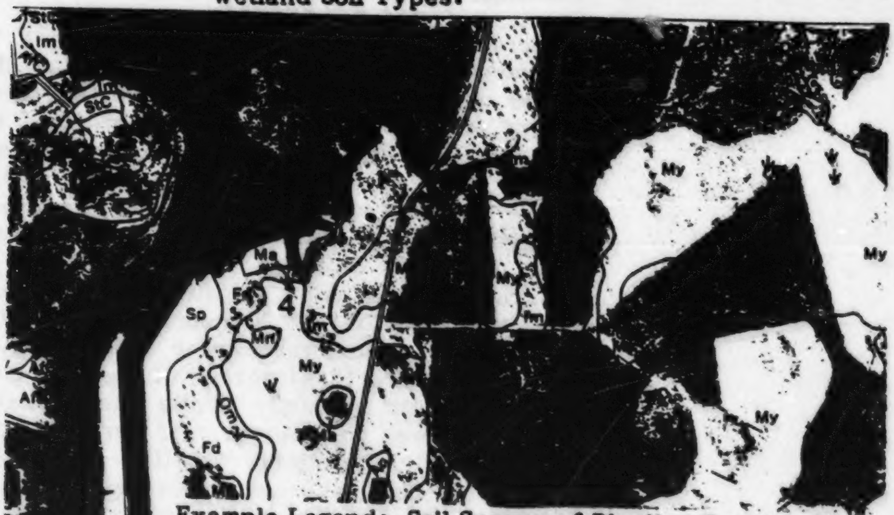
Figure 4-12. Types of Wetland Aquatic Vegetation


EMERGENTS
SURFACE PLANTS
SUBMERGENTS
Height (ft.)
5
4
3
2
1
Tall Meadow Emergents
Short Meadow Emergents
Robust Emergents
Narrow-Leaved Marsh Emergents
Broad-Leaved Marsh Emergents
Sub-Shrubs
Floating Plants
Floating-Leaved Plants
Submergents

Source: Adapted from Golet 1973.

Microbial processes affect nutrient uptake and control denitrification under anaerobic (oxygen lacking) conditions. The cation exchange capacity influences the uptake of certain elements, and soil structure affects phosphate binding. Permeability affects percolation rates, which control residence time in the wetland. In a hydrologically isolated wetland, permeability controls whether interaction with groundwater or evapotranspiration is the major influence on the water budget. Figure 4-12 indicates the distinction of soil types and wetland areas based on soils types from soil conservation service maps.

Figure 4-13. Use of Soil Conservation Service Maps for Identifying Wetland Soil Types.



Example Legend: Soil Survey of Pinellas County, FL
Au - Astor soils
Mn - Manatee loamy fine sand
My - Myakka fine sand

The two major distinctions of soil types in wetlands are mineral and organic. Most soils in southeastern wetlands are organic. Pocosins, Carolina Bays, cypress domes, Atlantic White Cedar swamps and some river floodplains typically are characterized by peat soils (EPA 1983). Such soils typically have higher cation exchange capacities than mineral soils; however, they are also more sensitive to pH. This needs to be considered when determining whether a wetland can receive wastewater without deleterious effects.

Richardson (1985) also has shown that organic soils with low amounts of extractable aluminum may be less able to remove phosphorus than mineral soils. If nutrient removal is an objective of using wetlands, this should be considered. A soils assessment may be required to not only analyze impacts to wetlands, but also the degree of uptake or assimilation that can be achieved.

4.4.3 Wastewater Assimilation and Long-term Use Potential

Predicting a wetland's ability to assimilate wastewater is complex. Soil characteristics, vegetation and microorganisms affect assimilation and vary from one wetland to another as well as within one wetland. Water depths and detention times can fluctuate if the wetland receives runoff from upstream or upland areas. Furthermore, inputs of precipitation and other climatic parameters, such as temperature, are not predictable. Hence, the various wetland processes that result in wastewater assimilation, such as biological uptake and sedimentation, can be fluctuating constantly.

Scientists and engineers have studied the ability of certain wetlands to assimilate or retain nutrients. Removal of nutrients is limited largely by detention time within the wetland and by the type of soil and vegetation. The ability of wetland soils to retain phosphorus seems to decline as wastewater continues to be applied. According to Nichols and Richardson (1983), nutrients can be retained during the growing season and be subsequently released during periods when either little vegetation growth takes place or when physical forces such as high water velocities encourage resuspension of soil particles. Nutrient removal is only effective, according to Nichols (1983), if large wetland areas are available for small wastewater flows (e.g., 50 percent removal with one hectare (2.47 acres) of wetland per 60 people served by the wastewater system). While these quantitative relationships provide general guidelines, nitrogen and phosphorus assimilation are affected by wetland specific characteristics indicating the need to assess assimilative capacity on a site-specific basis. Efforts to predict the ability of wetlands to retain heavy metals and other pollutants have not been so extensive, but many of the same variables, namely pH, soils and vegetation, affect the assimilation of metals and other constituents.

Assessment of assimilative capacity needs to be conducted for specific wetlands, particularly under the conditions of a Tier 2 discharge. The major processes responsible for wetlands assimilative capacity are summarized in Table 4-2.

Management strategies, as wella s structural engineering options, continue to be developed to enhance assimilation and the long-term potential for a wteland's use. Analysis of the evaluation components described in the previous section will improve the ability to assess assimilative capacity. This, in turn, will help identify those wastewater management and structural options that help maintain natural wetland functions and values. The better the natural wetland is maintained, the greater its potential for long-term use.

Table 4-2. Major Processes Affecting Wetland Assimilative Capacity

Geomorphology

Soils:
- Mineral soils with extractable aluminum have greater potential for phosphorus assimilation than organic soils with little extractable aluminum
- Soils with higher microbial activity provide greater nitrogen assimilation
- Anaerobic soil conditions are essential for denitrification, which can be a major N removal pathway

Hydrology/Meteorology

Flow patterns:
- Meandering channels with slow moving water and large surface areas increase pollutant removal by sedimentation
- Shallow, sheet flow patterns enhance some assimilative processes
- Deeper pools can sometimes improve the potential for denitrification
- Mixed flow patterns, such as indicated by the above characteristics, have higher potential for assimilation

Climate:
- Runoff from precipitation events can increase flow through times and short circuit assimilative processes
- Seasonal cycles affect growth and die-off patterns which control uptake and release of pollutants
- Temperature affects reaction kinetics and microbial activity

Water Quality

Chemistry:
- The form of nutrient entering a wetland can affect its assimilation by biological components
- pH and dissolved oxygen levels can affect assimilation processes; dissolved oxygen must be present for some processes (nitrification) and absent for others (denitrification)

Ecology

Vegetation:
- Thickly vegetated wetlands are useful for filtering suspended solids and organics
- Vegetation helps achieve sheet flow, which enhances other assimilative processes
- Mixed stands of vegetation may be more effective in assimilating metals due to selective uptake
- Nutrient and metal uptake by vegetation can be important, but may not be a final sink due to seasonal die-off and cycling
- Provides a substrate for some microbes important to assimilative processes

Microbes:
- In anaerobic soils, provide for N removal by denitrification
- Primarily responsible for BOD removal, optimal removal is obtained where large surface areas are available for microbial growth and an adequate supply of dissolved oxygen exists.

4.5 USER'S GUIDE

The primary user of the Chapter 4 guidance is the potential discharger. Chapter 4 contains three major sections: Preliminary Site Screening, Alternatives Comparison and Detailed Site Evaluation. If a wetlands discharge is to be considered seriously, these tasks must be conducted sequentially.

The tasks outlined are essential to:

1) Information required by permit application
2) Engineering planning
3) Engineering design
4) Determination of effluent limitations
5) Environmental review components of the Construction Grants Program
6) Post-discharge monitoring.

The importance of thoroughly conducting the tasks outlined in this chapter, in conjunction with contacting the appropriate regulatory agencies, is evident. Since some of the information may be needed by regulatory agencies as well, the applicant and regulatory agency should be able to achieve some economies by coordinating data gathering and analysis functions.

The focus of the User's Guide is the preliminary and detailed site evaluation. The User's Guide for Preliminary Site Screening should lead, through a series of checklists, to a relatively quick (and cost-effective) determination of feasibility. If certain constraints are identified for a particular wetland site, its infeasibility can be ascertained readily. If the site still appears feasible after the preliminary screening, the more detailed analysis should be conducted. Figure 4-14 indicates how preliminary and detailed site screening relate to the decision making process.

4.5.1 Preliminary Site Screening

The five elements listed in Section 4.2.2 comprise analyses that can be easily and cost-effectively conducted to determine obvious constraints to using wetlands for wastewater management. Table 4-3 presents the work tasks providing the information necessary to fill out Form 4-A and to assess the feasibility of the wetlands discharge alternative. Form 4-A is the basis for the preliminary site screening assessment. Permitting and effluent limitation considerations also are introduced at this point in the planning process. Immediate regulatory obstacles should be identified at this stage. Other regulatory issues are raised in later sections as they affect more detailed evaluations, engineering design, determination of effluent limitations and monitoring.

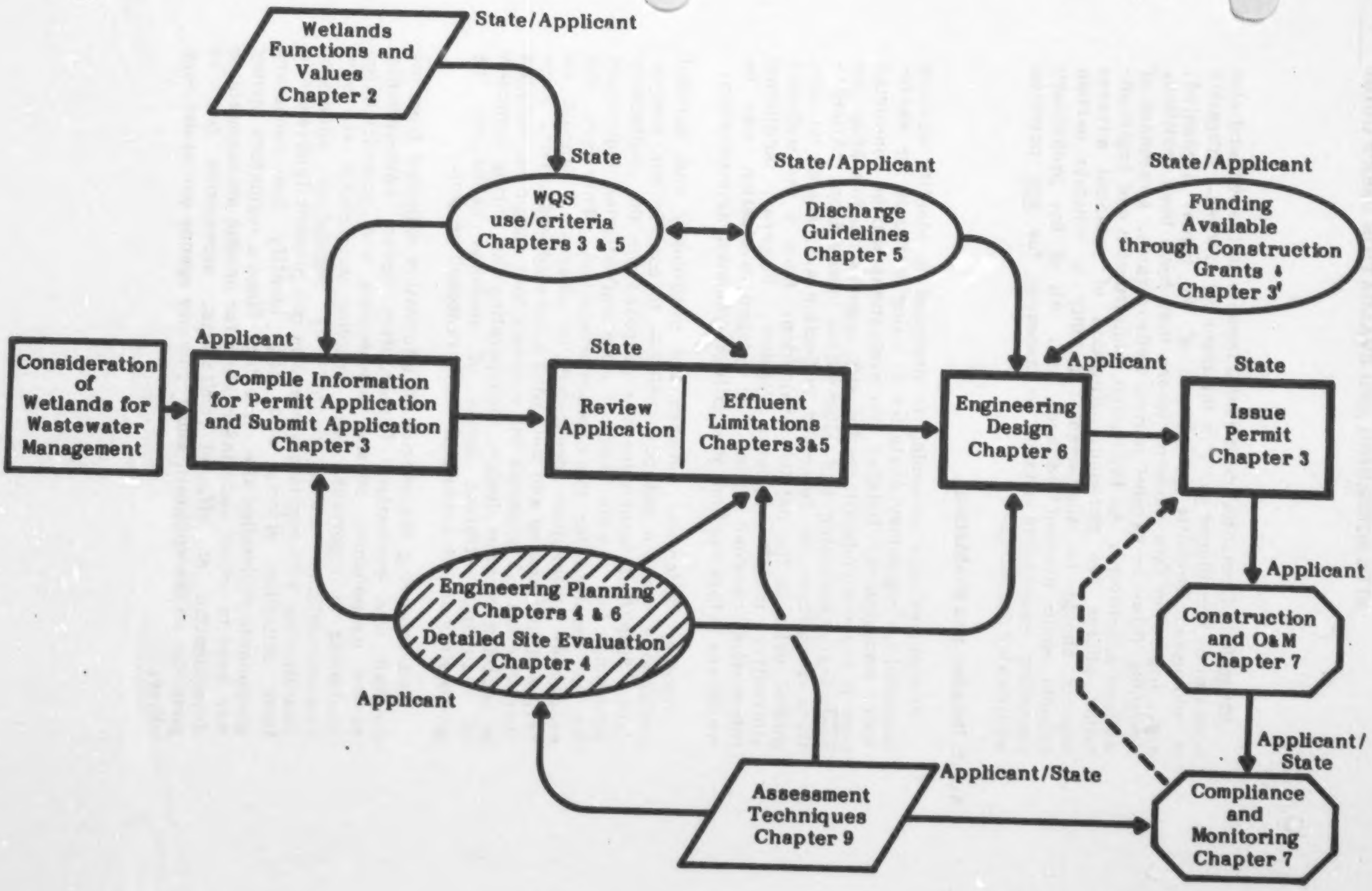

Wetlands Functions and Values Chapter 2
State/Applicant
State
WQS use/criteria Chapters 3 & 5
State/Applicant
Discharge Guidelines Chapter 5
State/Applicant
Funding Available through Construction Grants & Chapter 3'
Consideration of Wetlands for Wastewater Management
Applicant
Compile Information for Permit Application and Submit Application Chapter 3
State
Review Application
Effluent Limitations Chapters 3&5
Applicant
Engineering Design Chapter 6
State
Issue Permit Chapter 3
Applicant
Construction and O&M Chapter 7
Applicant/State
Compliance and Monitoring Chapter 7
Engineering Planning Chapters 4 & 6
Detailed Site Evaluation Chapter 4
Applicant
Assessment Techniques Chapter 9
Applicant/State

Figure 4-14. Relationship of the Handbook to the Decision Making Process.

Mitigation of potential detrimental impacts to the wetland also needs to be considered early in the planning process. Mitigation is addressed implicitly by several of the issues presented: e.g., improving flow patterns where they have been modified, designing flows to parallel normal hydroperiods, awareness of wetland sensitivity. As the design, construction and implementation phases are pursued, mitigation of potential adverse impacts should be addressed. Inability to mitigate certain impacts could prevent wetlands use. All of the preliminary screening components should be assessed for any potential wastewater discharge.

4.5.2 Detailed Site Evaluation

Preliminary site screening is designed to identify obvious technical or regulatory obstacles to using wetlands for wastewater management. Detailed site evaluations will be conducted only if the wetlands alternative still appears feasible after the preliminary screening and alternatives comparison. Alternatives comparison, as described in Section 4.3, should be conducted prior to the detailed evaluation. Even if the wetlands alternative initially appears feasible, however, additional information obtained from the detailed evaluation may be necessary before the final alternatives evaluation determination.

Another difference between the preliminary and detailed evaluations are the methods available to compile and analyze data. Simplified techniques are proposed for the preliminary screening, but a wide range of more sophisticated techniques may be required for the detailed evaluation. Therefore, the assessment techniques presented in Chapter 9 should be reviewed in planning and designing a detailed evaluation. Further, Section 9.2 presents the concepts that should be included in sampling program design, incorporating the tiering approach of requiring different levels of analyses based on the uncertainty or risk associated with a proposed project.

Understanding the overlap of information collected from the detailed site evaluation, Construction Grants environmental review components, on-site assessments and post-discharge monitoring is important. The sampling components are only recommendations until adopted by regulatory agencies. Coordination with regulatory agencies can present duplication in later collection efforts and help identify the necessary components of detailed site screening. Since a regulatory agency may need to collect some information for on-site assessments or determination of effluent limitations, agreements may be possible; so the applicant and regulatory agency can assist each other.

Detailed site screening provides the information necessary for engineering design decisions. Several alternative approaches to design may be available, based on wetland type and sensitivity. In other cases, only one design option may be appropriate. If a wetland is particularly sensitive to flow or pH changes, for example, the detailed site evaluation needs to identify that sensitivity so it can be incorporated into engineering design. Some wetlands may have an existing data base, whereas others will not. Each wetland, therefore, needs to be assessed on a site-specific basis, and the level of analyses designed accordingly.

Given the variability needed for different levels of analysis, Chapter 9 summarizes available assessment techniques. Chapter 9 indicates when a technique might be used, how it relates to decision making, resource requirements and several other attributes that could determine the optimal technique to apply. Form 4-B leads a potential applicant through the elements of a detailed site evaluation.

Table 4-3. Preliminary Site Screening Work Tasks.

A. WASTEWATER CHARACTERISTICS AND MANAGEMENT OBJECTIVES.

1. Determine population served.
2. Identify sources of wastewater in the area to be served.
3. If residential sources, use the accepted value for the study area for water consumption per person to estimate peak flow.
4. If commercial sources, estimate peak flow based on use.
5. If industrial sources, estimate peak flow based on type of process and historical flow records.
6. If industrial source, determine the extent of pretreatment and procedures for handling effluent when pretreatment process is not functioning.
7. Based on the sources of influent, estimate wastewater characteristics for each.
8. Identify wastewater treatment processes anticipated to provide a minimum of secondary treatment prior to discharge.
9. Check the functions you would like the wetland to perform:

Disposal ________________

Nutrient removal ________________

If so, what constituents ________________

Disinfection ________________

Solids Reduction ________________

Organics Reduction ________________

Neutralization of:

Low pH ________________

High pH ________________

Biocides ________________

Dyes ________________

Other ________________

B. WETLAND TYPE.

1. Contact wetland biologist with either the state Department of Natural Resources (or equivalent) or the U.S. Fish and Wildlife Service district office.
2. Determine through above contacts if the wetland area being considered has been mapped.

   If so, identify wetland type using Cowardin classification system.

   If not, determine type through use of photographs or field trip.
3. If state has an adopted method of identifying wetland type, use that system in addition to above.

Table 4-3. Continued

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4. Based on classification of wetland type, determine if wetland is an endangered or unique wetland (see Section 2.4).

5. Determine if the wetland is habitat for protected species (contact state agencies or U.S. FWS).

C. WETLAND SIZE AND TOPOGRAPHY.

1. Determine the general size of the wetland area.

2. Estimate what portion of the wetland will be impacted by the discahrge.

3. Use topographic maps to evaluate the topography of the wetland.

4. Characterize the topography of the watershed containing the wetland.

5. Using a reference such as Adamus and Stockwell (1983) relate topography to potential wetland functions and uses.

D. WETLAND AVAILABILITY AND ACCESS.

1. Determine who owns the wetland area being considered. For large systems, such as cypress strands, check for multiple owners. See the maps provided with city or county tax records, identifying owners of wetland parcels proposed for use.

2. Assess the general availability of the wetland as a receiving water with the owner.

3. Determine the distance to the wetland(s) from the existing or proposed treatment facility.

4. Assess the feasibility for controlling access to the wetland area.

5. Identify access points such as roads, bridges, rights-of-way and stream channels.

E. ENVIRONMENTAL CONDITION AND SENSITIVITY.

1. Topographic and land use maps for the wetland area should be obtained. Contact the nearest U.S. Geological Survey office for topographic maps and the local or regional planning commission for land use maps.

2. Conduct a site investigation with the maps obtained above. Noting when the maps were produced, mark areas that have changed since the maps were produced and indicate the types of change.

3. Identify obvious pollutant sources to the wetland (e.g., connected impervious areas, treatment facilities).

4. At the prospective site, take pictures of the wetland and adjacent areas.

5. Examine the wetland for signs of impacts (e.g., modified flow patterns from roads intersecting wetland, dying vegetation, algal scum on water surface, odors, etc.). Document indications of impacts.

6. Review Chapter 8 and, based on wetland type, assess the potential sensitivity of the wetland to the projected flows and effluent characteristics.

7. Identify and characterize water bodies into which the wetland discharges.

Table 4-3. Continued

F. PERMITTING CONSIDERATIONS AND EFFLUENT LIMITATIONS.

1. Contact the state regulatory agency responsible for permitting municipal wastewater discharges.
2. Identify what information will be required from an applicant to obtain a permit for wetlands-wastewater discharge.
3. Through discussions with agency personnel, ascertain the process for obtaining a wetlands discharge permit and how effluent limitations will be established.
4. Evaluate the permit application information required, likelihood of obtaining effluent limitations, what treatment levels will likely be required to meet effluent limitations, the schedule for obtaining effluent limitations in light of data availability and the project implementation schedule.

FORM 4-A Wetlands-Wastewater Management System—Preliminary Site Screening Checklist

A. WASTEWATER CHARACTERISTICS AND MANAGEMENT OBJECTIVES.

1. What is the projected wastewater flow to the wetland? ________

2. What percentage is derived from the following sources?

   Domestic (residential) ________

   Commercial ________

   Industrial ________

3. What are the projected treatment plant influent characteristics for the following parameters?

   BOD ________ Suspended solids ________

   Fecal coliforms ________

   Others ________________

   ____

   If industrial component, list characteristics

   ________ ________

   ________ ________

4. Are you expecting to consider the wetland as part of the treatment process?

   Yes ________ No ________

   If yes, check feasibility with state regulatory agencies.

Assessment:

* If the influent has a significant industrial component, a wetland is **not recommended** for use. Exceptions are:

1) Industrial effluent is relatively low percentage of total flow (e.g., less than 10%).
2) Pretreatment process can be verified as sufficient, and an emergency back-up for pretreatment exists (e.g., holding ponds).
3) Contains no toxics or hazardous materials that can bioaccumulate, with remaining characteristics being similar to domestic effluent.

All three of these conditions should be met for the wetland alternative to be considered further.

* If the wetland is planned as part of the secondary treatment process, **abandon the alternative.** Most wetlands are waters of the U.S. and require an effluent discharge to have a minimum of secondary-treatment.

* If the wetland is proposed as part of advanced treatment, check with state regulatory agencies and EPA to determine if such use is feasible. In most cases it is **not approvable.**

B. WETLAND TYPE.

1. What type of wetland is being considered for use?

   Common name ________

   Cowardin classification ________

FORM 4-A Continued

State-approved classification ________________ (if applicable)

2. Is the wetland endangered or unique (based on Section 2.4)?
Yes ________________ No ________________ Uncertain ________________

3. What, if any, protected species are potentially found in this wetland type in this area (see Section 9.4)? ________________________________

Assessment:

* If the wetland area is considered endangered or unique **its use is discouraged.**

* If the presence of protected species is suspected, field confirmation should be conducted. If evidence of protected species or their habitat exists, **another site should be found.**

C. WETLAND SIZE AND TOPOGRAPHY

1. What is the "effective" size of the wetland?

Total area of wetland ________________

Area downgradient from location of proposed discharge (if a measurable hydraulic gradient exists) ________________________________

Estimate of percent of that area impacted by discharge ________________

2. What is the proposed hydraulic loading rate to the wetland in inches per week?

Effective size of wetland ________________ acres ________________ sq ft

Flow rate ________________ mgd ________________ cubic ft/day

________________ cubic ft/week

$$\frac{\text{Flow rate}}{\text{size}} = \_\_\_\_\_\_\_\_\_\_ \frac{\text{ft}^3/\text{wk}}{\text{ft}^2} = \_\_\_\_\_\_\_\_ \text{ ft/wk}$$

$$= \_\_\_\_\_\_\_\_ \text{ in/wk}$$

3. Based on these calculations, potential depths and residence times can be estimated under some conditions. See Section 9.5 for a discussion of the methodologies. What topographic features (e.g., shallow, meandering, circular, etc.) help meet identified wastewater objectives? (See Adamus and Stockwell 1983)

____

____

4. Does the proposed wetland site have the topographic features identified in #3 above? Yes ____ No ____
If yes, what features are important, and why?

____

____

____

FORM 4-A Continued

Assessment:

* One inch per week serves as a general, conservative hydraulic loading rate. If the loading rate is greater than five inches per week, however, **additional area likely is needed.** Detailed site evaluation of additional sites will be needed in this situation to determine feasibility of the wetlands alternative.

* Topographic features will likely not preclude further investigation of the wetland site although incompatible features for wastewater management objectives could require additional engineering considerations.

D. WETLAND AVAILABILITY AND ACCESS.

1. Who currently owns the wetland being examined? ______________________

____

2. Will the owner consent to have the wetland used for wastewater management?

Yes ____________ No ____________

3. What methods will be used to assure availability and access?

Purchase ____________ Long-term lease ____________

Easement ____________ Land-exchange ____________

Other ____________________

4. Does the state require ownership of the wetland if it is to be part of a wastewater management system?

5. What type of access to the wetland is available?

None (fenced) ____________

Limited (wet soils, stream channels) ____________

Easy (roads, bridges) ____________

6. What is the distance from the existing or proposed treatment facility to the wetland? ______________________

If more than one wetland or wetland areas are being used, what are the distances to these systems? ______________________

____

Assessment

* If arrangements for the use and, ultimately, control of wetland cannot be made, **another wetland site or alternative should be pursued.**

* If the state requires ownership of a wetland that is part of a wastewater management system, **ownership by some mechanism must be achieved.**

FORM 4-A Continued

* A proposed wetland site should be adjacent to existing or proposed facilities to minimize pumping costs. Pumping costs to a proposed site should be evaluated to assess site feasibility.

E. ENVIRONMENTAL CONDITION AND SENSITIVITY.

1. Based on an analysis of topographic and land use maps, and a site visit, what changes have occurred in the wetland's watershed that might have affected the wetland?

Roads ______________ Fill ______________

Draining ______________ Adjacent impervious area ______________

Construction ______________ Timbering ______________

Other ______________

2. Have any of the above caused obvious changes in flow patterns?

Flows in the wetland , Yes ______________ No ______________

Flows to the wetland , Yes ______________ No ______________

Flows from the wetland , Yes ______________ No ______________

3. What is the nature and extent of potential pollutant sources to the wetland?

Effluent discharges ______________ Flows ______________

Type ______________

Nonpoint sources __________

Impervious area ______________ Proximity of impervious area ______________

Percentage of watershed ______________

Construction activity ______________ Erosion ______________

Other ______________

4. Is there evidence of a water line on trees or other vegetation?

Yes ______________ No ______________

If yes, what is the height above the ground? ______________

5. Are any trees or other vegetation dying?

Yes ______________ No ______________

6. Do vegetation appear stressed, based on dying branches or other signs?

Yes ______________ No ______________

7. Are algal mats or other floating vegetation (e.g., duckweed) predominant on the water's surface?

Yes ______________ No ______________

Form 4-A Continued

8. Based on type, to what changes might the wetland be most sensitive?

Flow ____________ pH ____________

Nitrogen ____________ Phosphorus ____________

DO ____________ Other ____________

Assessment

- Use of pristine wetlands should be **discouraged**, particularly if nearby wetlands already have been influenced by development, road building, etc.
- A wetland that has experienced changes in natural flow patterns, resulting in the wetland drying out, should be given **higher priority** for a wetlands discharge.
- Wetlands already exhibiting signs of stress should be **evaluated carefully** and in more detail to determine if a wastewater discharge would improve or intensify existing stress.
- If a wetland is sensitive to a factor(s) associated with wastewater (e.g., flow or pH adjustments), its use is **discouraged** unless the detrimental effects can be mitigated.

F. PERMITTING CONSIDERATIONS AND EFFLUENT LIMITATIONS.

1. Is it within your capabilities to obtain the information required for a discharge permit application?

Yes ____________ No ____________

2. Has the state regulatory agency indicated that the discharge can be permitted?

Yes ____________ No ____________

3. If yes, have the potential permit conditions been identified?

Yes ____________ No ____________

If yes, list ____

____

____

4. Can effluent limitations be obtained to coincide with design and implementation schedules?

Yes ____________ No ____________ Uncertain ____________

Assessment

- If questions remain about the ability to obtain a permitted wetlands discharge, and associated permit conditions, **proceed with this alternative with caution.**
- Effluent limitations and the point where the permit will be enforced are important to design decisions and can conceivably affect feasibility. While other scientific or engineering considerations might appear positive, **regulatory concerns could affect implementability.**

Form 4-A Continued

G. SUMMARY OF ASSESSMENT

If this assessment presents no constraints, the Alternatives Comparison task should be conducted. If the wetlands alternative remains feasible, the detailed site evaluation, Form 4-B, should be completed.

If this assessment indicated the prospective wetland site may not be feasible, mitigation of some constraints (as indicated) may be possible. If mitigation is not possible, preliminary screening should be conducted for other potential wetland sites, if available. If they also exhibit limitations for wastewater management use, the wetlands alternative should be abandoned and other alternatives pursued.

FORM 4-B. DETAILED SITE EVALUATION ASSESSMENT

A. WETLANDS IDENTIFICATION.

1. Identify wetland boundaries.

   Approaches

   a. Use U.S. FWS classification with modifiers (Cowardin 1979).
   b. Use state-approved methods based on vegetation, soil types or hydrology.

2. Define determination of "effective wetland area." (Must consider likely discharge location and structure.)

   Approaches

   a. For an isolated system, the wetland area impacted by a discharge depends on the size of flow and wetland.
   b. If sheet flow, tracer studies can be used to indicate flow paths.
   c. If channelized flow, the wetland downgradient from the discharge will be affected.
   d. Interconnecting channels and direction of hydraulic gradient should be identified.

   Indicate these determinations on a map, which may be included with a permit application.

B. WETLANDS VALUES AND USES.

1. Estimate wetland values.

   Approaches

   a. For a preliminary assessment, relate information in Chapter 2 to the wetland being evaluated. Techniques in Section 9.4 may also be useful.
   b. For a more detailed assessment, use technique developed by Adamus (1983) or equivalent in Section 9.4. The Adamus technique has been accepted jointly by the U.S. FWS, EPA and Corps of Engineers as the preferred system for determining wetland values.

   The assessment of wetland values integrates land use, geomorphological, soils, water quality and ecological considerations.

2. Define potential wetland uses, existing and future. Use techniques discussed in Chapter 9 to ascertain which functions and values listed in Table 2-2 are important in the wetland being investigated.

   The potential for a wetland to provide one or more of these uses in the future should be evaluated, in addition to those currently exhibited.

C. WATERSHED CHARACTERISTICS AND CONNECTIONS.

1. General watershed characteristics should have been identified by previous tasks. At a minimum, the following should be evaluated:

   a. Existing land use
   b. Development trends
   c. Topography
   d. Proximity to impervious areas
   e. Drainage patterns within watershed
   f. Area of land draining into wetland
   g. Culverts, ditches or other structures influencing drainage patterns
   h. Type and quality of water body into which the wetland discharges.

FORM 4-B Continued

2. Determination of whether the wetland is connected hydrologically to or isolated from surface water flows.

   Approaches

   a. Use a topographic map and/or aerial photography to identify channelized flows into or out of the wetland.
   b. Use the same tools to assess overland flow into or out of the wetland.
   c. Supplement with a site visit to field truth maps and estimate flow patterns.
   d. If development has occurred around the wetland, identify what ways, if any, hydrologic connections have been affected.
   e. Note presence of berms, levees or other flow modifiers.

3. Determination of whether wetland is hydrologically connected to or isolated from groundwater flows.

   Approaches

   a. Obtain subsurface maps from the USGS and estimate substrate underlying the wetland. Determine if area is karstic.
   b. Obtain groundwater maps indicating primary recharge areas.
   c. Analyze maps or determine hydrologic gradient for indicating general direction of groundwater management.
   d. Collect and evaluate core samples for evidence of hardpan, or clay layer.
   e. If the system is connected hydrologically to surface waters, characterize downstream systems that could be impacted by a wastewater discharge
   f. If the system is connected to groundwater flows, identify groundwater uses downgradient from the wetland and distance to wells, if any.

   The use of wetlands located in karstic areas that serve as prime groundwater recharge areas may need to be avoided. The soil characteristics and presence or absence of a hardpan are more important in karstic areas.

D. WATER BUDGET AND HYDROPERIOD.

1. Determination of the water budget.

   Approaches

   a. Collect the information necessary to determine water storage, based on the following formula:

      $$\Delta S = P + Q_1 + Q_2 + G_1 + W - Q_2 - G_2 - E$$

      See Section 4.4.2 for definitions. See Chapter 9 for the variety of techniques available for obtaining these data. Depending on objectives and available data, either annual or monthly water budget should be determined.

   b. If surface water flows have not been measured by existing stage records, the use of weirs may be necessary to constrict surface water inflows and outflows so they can be measured.

   c. If existing groundwater data indicating velocity and direction of water movement are not available, wells may need to be drilled or estimates made based on transmissivity, permeability and other soils characteristics.

2. Estimation of hydroperiod.

   Approaches

   a. As indicated by Figure 4-10, hydroperiod is largely dependent on both regional and local precipitation patterns. Assessment of precipitation patterns gives some indication of general trends.

FORM 4-B Continued

b. Hydroperiod relates primarily to the length of inundation, but also to the depth. Certain wetlands may not dry out totally, but the depth of standing water varies and could be important to certain wetland functions (e.g., could affect whether aerobic or anaerobic conditions exist). Therefore, some estimate of the variability of water depth should be made.

c. Well data, water marks on trees, historical stream gage records from nearby streams, historical precipitation patterns and historical aerial photographs can all provide insights or information relevant to hydroperiod and/or water budget. The following process could be helpful in estimating hydroperiod:
- Examine USGS stream flow records from adjacent water bodies, if hydraulically connected.
- Examine groundwater logs of nearby wells, if available.
- Analyze National Weather Service precipitation and evapotranspiration records for the watershed.
- Estimate if conditions examined are representative of normal, wet or dry conditions (based primarily on historical precipitation records)
- Assess how hydroperiod would change under different hydrometeorological conditions.
- Evaluate one year of data, if possible, to estimate seasonal changes.
- Verify analysis with field investigations, if possible.

d. Ideally, hydroperiod would be determined based on long-term monthly evaluations of the water budget.

e. Flooding from adjacent surface waters should be considered carefully.

3. Depth and Residence Time. These may be important for some wetlands-wastewater systems, particularly hydrologically connected Tier 2 discharges. As part of preliminary design, estimations of these two variables might be important. Section 9.5 discusses approaches to their evaluation, using Manning's equation.

E. BACKGROUND WATER QUALITY CONDITIONS.

1. Based on the presence of other pollution sources, development of the watershed or modifications to the wetland, estimate the extent to which existing water quality conditions reflect natural background conditions or modified conditions.

2. Determine what parameters should be analyzed to define background conditions.

Approaches

a. The design of the sampling program should incorporate seasonal influences (see Section 9.2).

b. Flow should be measured in conjunction with collecting water quality samples. Interpretation of water quality data is dependent on knowing the flow at the time of sampling.

c. Recent precipitation events and flow patterns are also helpful in interpreting water quality data. What was the precipitation pattern, and associated flows, for the two weeks prior to sampling? Are sampling conditions indicative of low or high flows? What influence does stormwater have on water quality conditions existing at the time of sampling?

d. Selection of parameters will depend on tiering, wastewater characteristics, wetland values and uses, and downstream conditions. Also assess what parameters may be necessary for environmental review criteria (if Construction Grants are involved), site-specific standards or effluent limitation analyses (conducted by state) or post-discharge monitoring.

Form 4-8 Continued

F. WETLAND ECOLOGY.

1. Identify predominant vegetation species and associated habitat.

   Approaches

   a. Use techniques for determining the diversity of submergent, emergent and floating vegetation.
   b. Note the pattern of vegetation growth, particularly in conjunction with identifiable flow patterns in the wetland.
   c. Use the determination of predominant vegetation types to help confirm the identification of wetland type and boundaries.

2. Relationship of vegetation type to wildlife.

   Approaches

   a. Use the tables suggested by Chapter 9 to identify the types of wildlife typically found in association with certain vegetation.
   b. Determine the percent of open water (that amount not covered by vegetation) as it affects waterfowl breeding and habitat.
   c. Conduct the vegetation survey in conjunction with the projected species assessment, identifying where present typical habitat and/or evidence of protected species.

3. Determine the effects of vegetation type on assimilative capacity based on the documented ability of certain vegetation for nutrient uptake (see Section 9.4) and adjusting to changes in hydrology.

   Approaches

   a. Evaluate the sensitivity of vegetation types to changes in hydrology or water chemistry (see Chapter 8).
   b. Assess nutrient uptake potential based on vegetation type if nutrient removal is being sought.

   Many factors combine to affect the assimilative capacity of a wetland, including soil type, density and type of vegetation, geomorphology and flow patterns. Assimilative capacity is discussed further in Chapter 5, as it affects the determination of effluent limitations, and Chapter 9.

G. SOIL CHARACTERISTICS

1. Determine soil type as organic or mineral.

   Approaches

   a. Use the list of wetland soils provided by the U.S. FWS to help determine if soils of the proposed site are wetland soils.
   b. Use soils maps provided by the Soil Conservation Service to estimate the predominance of mineral or organic soils.
   c. Obtain core samples and analyze grain size and organic content.

2. Evaluate the hydraulic and assimilative capacity of soils, including aluminum and iron fractions.

   Approaches

   a. Determine the soils' permeability and potential percolation rates through the soil profile.
   b. In conjunction with earlier analyses, confirm the presence or absence of a hardpan or clay layer underlying the wetland.
   c. Estimate the cation-exchange capacity of the soils and extractable aluminum content.
   d. Determine the depth of soil saturation to assess whether, and the conditions under which, soils are aerobic or anaerobic.

Form 4-8 Continued

e. Based on the characterization of soil type, estimate the nitrogen and phosphorus removal potential of the soils.

f. Evaluate the pH sensitivity of wetland substrates (e.g., bog).

The assessment of seasonal influences and potential assimilative capacity affect both sampling program design and interpretation of data. Ultimately, this information affects engineering design, construction, O&M and post-discharge monitoring decisions.

H. SUMMARY OF DETAILED SITE EVALUATION

Figure 4-13 indicates how the detailed site evaluation coincides with other assessments in determining the feasibility or design of a wetlands wastewater system. Information gained from the evaluation (related primarily to wetland values and uses, and watershed characteristics and connections) could still prove the wetlands alternative to be infeasible. If the evaluation does not lead to eliminating the wetlands alternative, however, it provides the basis for design, construction, O&M and post-discharge decisions.

5.0 WATER QUALITY CRITERIA AND DISCHARGE CHARACTERISTICS

5.1 RELATIONSHIP OF CRITERIA TO PROGRAM REQUIREMENTS 5-2

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5.4 EFFLUENT LIMITS 5-19
- **5.4.1 Classification of Wetlands as Effluent- or Water Quality-Limited**
- **5.4.2 Determination of Effluent Limitations for Effluent-Limited Wetlands**
- **5.4.3 Determination of Effluent Limitations for Water Quality-Limited Wetlands**
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  - o On-Site Assessments

5.0 WATER QUALITY CRITERIA AND DISCHARGE CHARACTERISTICS

Who should read this chapter? Primarily, regulatory personnel dealing with standards and effluent limits. Secondarily, engineers determining loading rates, required wetland size, etc.

What are some of the issues addressed by this Chapter?

- o What water quality standards criteria apply to wetlands?
- o Are conventional standards criteria appropriate for wetlands?
- o How do on-site assessments relate to effluent limits?

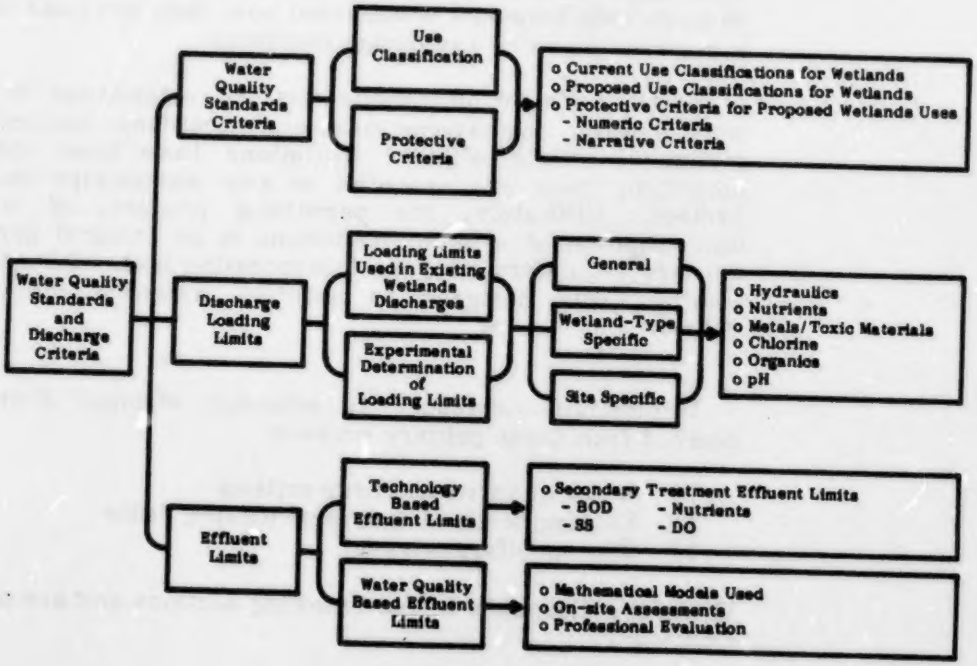
Water Quality Standards and Discharge Criteria
Water Quality Standards Criteria
Use Classification
Protective Criteria
o Current Use Classifications for Wetlands
o Proposed Use Classifications for Wetlands
o Protective Criteria for Proposed Wetlands Uses
- Numeric Criteria
- Narrative Criteria
Discharge Loading Limits
Loading Limits Used in Existing Wetlands Discharges
Experimental Determination of Loading Limits
General
Wetland-Type Specific
Site Specific
o Hydraulics
o Nutrients
o Metals/Toxic Materials
o Chlorine
o Organics
o pH
Effluent Limits
Technology Based Effluent Limits
Water Quality Based Effluent Limits
o Secondary Treatment Effluent Limits
- BOD
- SS
- Nutrients
- DO
o Mathematical Models Used
o On-site Assessments
o Professional Evaluation

Figure 5-1. Loading Criteria Considerations for Wetlands Discharges

5.1 RELATIONSHIP OF CRITERIA TO PROGRAM REQUIREMENTS

Criteria established to protect water use classifications are an integral part of the Water Quality Standards (WQS) program. From a wastewater management standpoint, these criteria ultimately control the degree of treatment required and loadings to the receiving water. When considering the use of wetlands, criteria are important to three major areas of decision making.

First, criteria to protect wetland uses are established through the WQS program. Conventional use classifications or associated criteria may not be applicable to wetlands or fully represent wetlands. Criteria established by the WQS program must be used as guidelines, but the applicability of these criteria to wetlands needs to be assessed as part of the standards review process.

Second, data have been collected from numerous research projects to assess "acceptable" loadings to wetlands. Loading rates and design criteria based on these data are intended to optimize renovation of wastewater and protect wetlands functions and values. While these criteria have not been confirmed through long-term and widespread use, they are used to provide a basis for planning and design decisions.

Third, effluent limitations must be established to maintain WQS criteria, downstream uses and acceptable loading rates to wetlands. While effluent limitations have been difficult to establish, they are essential to any wastewater management project. Ultimately, the permitting process, of which the determination of effluent limitations is an integral part, is the primary regulatory program incorporating both WQS criteria and loading limits designed to maintain wetlands functions and values.

Information necessary to establish effluent limitations is derived from three primary sources:

1) Water quality standards criteria
2) Existing wetland discharge loading limits
3) Site-specific analyses.

These are discussed in the following sections and are outlined in Figure 5-1.

5.2 WATER QUALITY STANDARDS CRITERIA

5.2.1 Criteria for Existing Wetland Modifiers

Existing water quality standards criteria are the basis for establishing loading rates, or effluent limitations, for any wastewater discharge. In the case of wetlands use certain limitations are encountered when applying existing standards criteria. Basically, the limitations relate to the applicability of existing criteria to wetlands.

In most instances the criteria applied to wetlands are those of the adjoining stream segment. These criteria may be obtained from state regulatory agencies. As indicated in Table 5-1, only Florida, North Carolina and Tennessee have established numeric criteria for wetlands systems; however, the numeric criteria do not account for the variability among wetlands. As a result, most states have the mechanism for establishing site-specific criteria, but this has proven to cause some administrative difficulties. North Carolina has used this approach through use attainability analyses. Florida and South Carolina have made some site-specific standard assessments but typically do not conduct such analyses. Where site-specific criteria differ from already promulgated criteria that may be applicable to that site, any criteria changes must go through the procedures as outlined in Section 303(c) of the CWA.

Table 5-1. WQS Criteria Associated with Wetlands

	DO	pH	Other
Alabama	-	-	-
Florida[1] - Experimental use	-	-	Hydraulic loading -0.5 - 1.0 in/wk
Georgia	-	-	-
Kentucky	-	-	-
North Carolina - Swamp water Subclass	<4.0	4.3	If "nutrient sensitive" no increases in N or P over ambient conditions
Mississippi	-	-	-
South Carolina	-	-	-
Tennessee - Fish and Aquatic Life	>3.0	6.5 - 8.5	-

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[1] The process of reviewing regulations concerning wastewater discharges to wetlands and associated criteria began during September 1985.

5.2.2 Protective Criteria for Wetlands

Establishing criteria to protect wetlands uses can be accomplished through existing generic regulations (Section 304(a), CWA) or through site-specific water quality analyses. The Water Quality Standards Handbook (EPA 1983) describes methods for developing general and site-specific water quality criteria.

An important consideration when establishing protective criteria for wetlands use clasifications or modifiers is the applicability of conventional parameters for measuring water quality. The parameter generally regarded as the best water quality indicator in free-flowing streams and lakes, dissolved oxygen, may not be an appropriate measure of water quality in wetlands. The reason is that many wetlands are intermittently wet and dry. During dry conditions, moisture may be in the form of soil saturation only, with no standing water. In such cases, water quality criteria based on dissolved oxygen has little meaning.

This situation raises several other questions. Should criteria for wetlands be based on low-flow or wet conditions? The assimilative capacity of many free-flowing streams, for example, is based on low-flow conditions and meeting criteria under those conditions. Will a discharge to a wetland system have more impact on the wetland and downstream waters in dry-periods or wet-periods, and how is this reflected in criteria and associated effluent limitations? How should naturally-fluctuating, intermittent moisture levels be incorporated into the water quality standards program?

Potential solutions to the situation include measuring water quality conditions by parameters other than dissolved oxygen or by considering seasonal criteria. If current use classifications such as fish and wildlife are applied to wetlands, then a dissolved oxygen of 5 mg/l probably would be required to meet fish and wildlife conditions. But, what about the situation found in a savannah, which is waters of the U.S., or in a swamp, where short-term natural dissolved oxygen levels reach zero? The fish and wildlife standards criterion of 5 mg/l probably is not appropriate in either situation; both require site-specific criteria which incorporate natural fluctuations or a new use classification or use subcategory that more closely depicts the uses to be protected.

If a new use classification or subcategory is developed, criteria to protect uses such as stormwater buffering or water purification may not require a dissolved oxygen level greater than 5 mg/l. Perhaps the most important parameter for protecting water quality and wetland processes is hydroperiod. Another method of protecting water quality may be through the use of biological indices, indicating the range of acceptable change. A combination of narrative and numeric criteria may be best, with numeric water chemistry parameters applied on a site-specific basis. Table 5-2 illustrates alternative approaches for establishing protective criteria for wetlands use classifications or modifiers by incorporating a combination of narrative and numeric criteria.

For a new wetland use classification or subcategory, **other parameters and associated criteria** may be required to protect those uses based on wetland type, conditions and downstream water bodies. North Carolina, for example, has a qualitative criterion of no increases in nitrogen or phosphorus in nutrient sensitive waters. These criteria need to be established on a site-specific basis. For a wetlands modifier such as Class B - Wetlands, criteria for standards parameters associated with Class B waters, such as water temperature or fecal coliforms, may be applied to the wetland as appropriate.

Table 5-2. Illustrative WQS Criteria for Prospective Wetlands Use Classifications or Modifiers.

Parameter	Criteria
1. Flow/Depth	- Seasonal water depths (monthly average) should not be modified by more than 20 percent.
2. Flow/Hydroperiod	- Wet and dry cycles within a wetland shall not be modified so as to cause loss of predominant species or wetlands processes. Natural drawdown periods will not be modified by more than 10 percent.
3. Biological Assemblage	- The Shannon-Weaver diversity index of benthic macro-invertebrates shall not be reduced to less than 75 percent of established background levels. - Predominant wetland vegetation (those comprising over 25 percent of population) shall not be reduced to less than 75 percent of established background levels in affected area.
4. Dissolved Oxygen	- During periods with standing or flowing water, established levels of daily DO fluctuations should not be modified more than 20 percent. - The maximum daily DO (monthly average) shall not be modified more than 20 percent. - Anoxic periods will not be increased by more than 20 percent. - During naturally dry periods, no DO criteria will apply.
5. pH	- For seasonal levels (monthly average of daily levels): levels of 6 or below will not be decreased below background levels or increased more than 1 unit; levels of 8.5 or above will not be increased above background levels or decreased more than 1 unit.

5.3 DISCHARGE LOADING LIMITS

Discharge loading limits for a wetland are based on the wetland's ability to assimilate wastewater. Studies have been undertaken to assess loading limits to various wetland types. A primary objective of such studies has been to document safe discharge levels (those that do not appear to degrade the system) and excessive discharge levels (those that lead to wetland stress or degradation).

The concept of generic loading limits, or those that apply to all discharges, is not appropriate for wetland systems due to the variation in wetland types. Some general guidelines, however, can be based on information from currently operating natural and created wetland systems. Hammer and Kadlec (1983), Chan et al. (1981) and Gearheart et al. (1983) provide information on design factors for meeting discharge objectives.

Ongoing wetland-wastewater systems in Florida, Michigan and elsewhere have been reviewed for loading criteria and removal efficiencies. These projects provide an example of the varying conditions and experimental activities that have taken place, hydraulic loading rates used and nutrient removal rates obtained. For the existing information on loading rates and removal potentials to be extrapolated to other wetlands systems, differences in wetland types, climate, vegetation assemblages, hydraulic loading, engineering features, water chemistry characteristics and uses should be evaluated.

Table 5-3 describes site screening, loading criteria and design options for several ongoing wetlands wastewater projects.

5.3.1 Hydraulic and Hydrologic Variables

Hydraulic loadings usually are described in terms of depth of water for a given period of time: for example, inches per week or gallons per week per acre (liters per week per hectare). Table 5-4 lists the hydraulic loading rates to several well-studied wetland-wastewater management systems throughout the country. Several aspects of this information are noteworthy. Many wetland types found in the Southeast are not represented on this list, indicating the lack of available information. The range of loadings shown for each wetland type, however, offers guidance for planning purposes.

The existence of an "effective" wetland area or zone of influence resulting from wastewater applications also should be considered in hydraulic analyses (see Figure 5-2). When wastewater is discharged to a wetland it may or may not impact the entire wetland depending on hydraulic gradient, location of

Table 5-3. Summary of Engineering Considerations at Selected Wetlands Discharge Sites

	Site Screening	Loading Criteria	Design Options
Clermont, FL[1] (1977-1979)	Ongoing discharge when studies began	Flow - 0.011 mgd. Experimental design examined loadings of 0.6, 1.5 and 3.8 inches/week.	Secondary treatment followed by three cell lagoon and chlorination. Distribution via gated pipe, 98 feet long.
Gainesville, FL[1] (1973-1982)	Site selection was based on experimental design of project. Factors included distance from wastewater source, size of wetland, representation of typical systems and access. Many other factors were included based on research orientation of project. Field surveys were conducted.	Flow - 0.016 mgd	Secondary treatment including lagoon and chlorination. Distribution via point discharge in middle of cypress dome.
Jasper, FL[1] (1916 - present)	Ongoing discharge when studies began	Flow - 0.221 mgd	Secondary treatment followed by two cell lagoon system prior to gravity flow into cypress strand. Only primary treatment for several years. Disinfection by chlorination.
Waldo, FL[1] (1935 - present)	Ongoing discharge when studies began	Flow - 0.092 mgd	Secondary treatment followed by gravity flow to a cypress strand. Only primary treatment for several years.
Wildwood, FL[1] (1957 - present)	Ongoing discharge when studies began	Flow - 0.400 mgd	Secondary treatment followed by discharge to percolation pond. Overflow discharges to canal leading to wetland. Disinfection by chlorination.
JSU, FL[2] (1967 - present)	Ongoing discharge when studies began	Flow - 0.68 mgd; BOD_5 - 20 mg/l (max) TSS - 20 mg/l (max); TKN - 11 mg/l (max) Flow equivalent to 0.3 inches/week.	Secondary treatment followed by discharge to mixed-hardwood swamp via channelized tributary (approximately 2000 feet long). Disinfection by chlorination.
GSWSA, SC[3] (proposed)	Considered seven factors: land cost, ownership, distance from wastewater source, site preparation, minimum depth to water table, soil permeability and habitat considerations	Effluent limitations into the wetlands have not yet been established. Planned flows could reach 3.7 mgd, not exceeding annual average of 1 inch/week.	Raw wastewater would be pumped into a multicellular aerated lagoon system; a completely suspended cell followed by three partially suspended cells. Disinfection by chlorination. Storage pond for emergency situations. Distribution via gated pipe. Detention time in cells - 7.5 days. Storage pond capacity - 2 weeks of average daily flows.
RCID, FL[4] (1971 - present)	Space available, proximity to wastewater source, distance from other land uses.	Flow - 2.12 - 3.5 mgd to cypress swamp - 0.85 mgd to overland flow wetland system Secondary standards adopted for BOD - 20 mg/l and TSS - 20 mg/l.	Secondary treatment with four methods of disposal; cypress swamps (102 acres), flow through wetland, spray irrigation and water hyacinth system. Polishing percolation and holding ponds are also part of the system. Disinfection by chlorination. Single point discharge to swamp.
Lake City, SC	Surveys by state archeologist and registered forester required prior to construction. Floodplain mapping required.	Flow - 4.2 mgd; BOD_5 - 15 mg/l; TSS - 20 mg/l; NH_3 - 2 mg/l; DO - 5 mg/l; Fecals - 200/100 ml.	Advanced treatment facility with microscreen filters and bio-discs. Disinfection by chlorination. Oxygen steps provide reaeration and dechlorination of effluent. Discharge by gravity flow into mixed hardwood swamp.

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[1] Project undertaken by city/Univ. of Florida
[2] Jacksonville Suburban Utility
[3] Grand Strand Water and Sewer Authority
[4] Reedy Creek Improvement District
[5] Includes only effluent/water quality monitoring - See Table III-1 for other types.

Table 5-4. Hydraulic Loading Rates to Selected Wetlands-Wastewater Systems.

Project	Wetland Type	Influent Type[1]	Wetland Area* (ha)	Average Dry Weather Flow* (m^3/day)	Inches/ Week
Natural Wetlands					
Whitney Mobile Home Park, Florida	Cypress dome	S	6	227	1.03
City of Waldo, Florida	Cypress strand	P	160[2]	454	0.07 (3.36)[6]
Reedy Creek Utilities, Florida	Cypress strand	S	41	7,570	5.1
City of Wildwood, Florida	Swamp	P	202	946	0.13
Jacksonville Suburban Utility, Florida	Swamp	S	-	2,574	0.3
Village of Bellaire, Michigan	Forested	S	15	1,136[5]	2.1
Hamilton Township, New Jersey	Freshwater tidal marsh	S	500	26,495	1.44
Town of Concord, Massachusetts	Shrub, deep marsh	S	19	2,309	3.24
City of Brillion, Wisconsin	Marsh	S	1,619[3]	757	0.013 (0.135)[6]
City of Clermont, Florida	Marsh	S	-	42	0.6 1.5 3.8
Houghton Lake Sewer Authority, Mich.	Peatland	S	243[4]	379	0.043 (3.76)[6]
Town of Drummond, Wisconsin	Bog	S	10	379	1.02

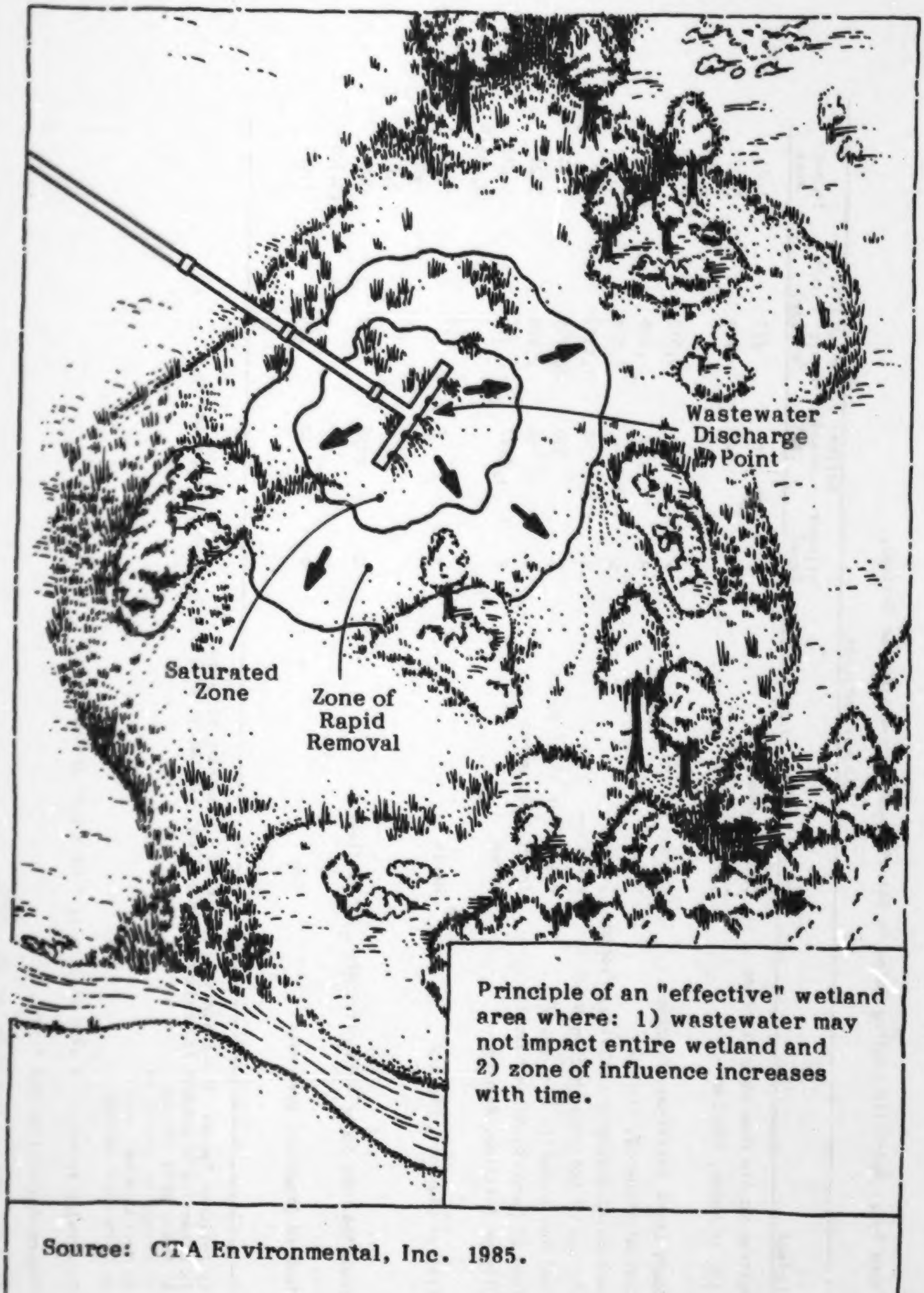
1) Influent Types: P - primary effluent; S - Secondary effluent
2) Effective treatment is achieved within 4 ha, but the total stand is approximately 160 ha.
3) Study area 156 ha
4) Effective area 3 ha
5) May-November only
6) Effective loading

Conversion factors: 1 m^3 = 264.2 gal; 1 ha = 2.47 acres.

*Approximate sizes and flows

Source: Adapted from Hyde, et al. 1982.

Figure 5-2. Schematic of the Zone of Affected Soil and Biomass.


Wastewater Discharge Point
Saturated Zone
Zone of Rapid Removal

Principle of an "effective" wetland area where: 1) wastewater may not impact entire wetland and 2) zone of influence increases with time.

Source: CTA Environmental, Inc. 1985.

distribution system and size of discharge related to size of the wetland. Further, a zone around the discharge serves to assimilate the wastewater most effectively. This zone grows larger as wastewater continues to be discharged and the assimilative capacity of the immediate area saturated. The major hydraulic and hydrologic variables that should be addressed by discharge guidelines are:

1) Discharge loading rates
2) Hydroperiod (timing and duration of wet and dry periods)
3) Area of inundation during wet and dry periods
4) Depth of inundation
5) Velocity
6) Average residence time
7) Estimation of sensitivity to hydraulic fluctuations.

Section 9.5 presents potential approaches for estimating water flows, velocities, depth, residence time and area of inundation in wetlands under natural conditions and with the addition of wastewater.

Discharge Loading Rates. Two hydraulic loading rates governing wastewater flows to wetlands often are used as guidelines. One is the application rate of **1 inch per week** over the area of the wetland (Odum 1976) and the other is **60 people per hectare** (2.47 acres) (Nichols 1983, Richardson and Nichols 1985). The latter, which equates to approximately 0.6 inch per week, is intended more as a determinant for nutrient removal; nonetheless, it addresses hydraulic loading. Based on the assessment of hydraulic loading rates to other systems, these rates may be low for some open systems. If a higher percentage of nutrient removal is desired, however, these rates are more appropriate. The basis for their use depends on specific objectives and the wetland system. Some cypress strands continue to function well at slightly higher levels, indicating the importance of whether a system is hydrologically isolated or open. Yet as a conservative basis to begin an assessment of loading rates during engineering planning, these loading rates are suggested. In establishing hydraulic loading rates based on an annual loading (e.g., inches/week), the effective size of the wetland needs to be determined as well as the total wetland size. The effective size also is known as the zone of influence or the area of impact of the discharge. Discharge loading limits should be based on the effective size if it differs from the total size.

Hydroperiod. The seasonal water level fluctuations in a wetland is known as its hydroperiod. One of the major aspects of evaluating a wetlands hydroperiod, if historical records are not available, is correlating the observed hydroperiod with long-term averages. Once a wetlands hydroperiod has been assessed, the hydraulic loadings can be scheduled to coincide with the natural hydroperiod. This can be important in wetlands where drawdown is essential to vegetative reproduction. Hydroperiod also impacts the species found in a wetland and competition between species. A significant alteration of hydroperiod can modify species composition. Cypress domes need a period of drawdown for reproduction whereas some marsh vegetation requires the continual presence of water. The calculation of hydroperiod is discussed in the Chapter 4 User's Guide.

Area of Inundation. In some hydrologically connected wetland systems, the addition of water will not cause a major increase in the area of wetland inundated. In hydrologically isolated systems, hydraulic loadings can significantly affect the area of inundation. Determination of the area of inundation is important for determining the residence time of waters in wetlands which is calculated from hydraulic loading and area. This, in essence, requires an understanding of wetland topography and hydrologic interconnections. See Section 9.5 for methods to estimate area of inundation.

Depth of Inundation. The depth of surface waters varies with hydroperiod and hydraulic loading. It also is related to the topography and the area of inundation. Hydraulic loadings to wetlands with constricted flow paths can result in greater depths or a greater area of inundation. Changes in depth of inundation can alter vegetation species and wildlife habitat. Water depth also can affect the denitrification process.

Differences in the normal depth and depths during runoff or flooding conditions also should be noted. Typically, for streams and rivers the cross-sectional area is determined for different stages. Then, for varying relocations, the flow can be calculated. This approach has applicability to wetlands for establishing the relationships between area, depth (stage), velocity, retention time and hydraulic loading. See Section 9.5 for methods to estimate water depths.

Velocity. Velocity is important to discharge rates for several reasons. Velocity from the discharge point(s) should be kept below the level that could lead to scour of sediment and damage to vegetation. This velocity needs to be balanced with that necessary to create scour in pipes to prevent clogging. Once in the wetland, velocities should be reduced if solids removal and sedimentation are desired. The upper limits of velocity for settling depend on particle size and type of solids. Velocity within a wetland depends on some of the relationships discussed earlier (hydraulic loading, area) as well as the roughness, or amount of vegetation and contour of wetland. See Section 9.5 for methods to estimate velocity.

Residence Time. To prevent the confusion in terminology between detention and retention time, residence time is used to express the length of time a water particle remains in the wetland, or its time of travel through the wetland. Residence time depends on the interrelationship between area if inundation, hydraulic loading and velocity. This may not be an important consideration if wastewater disposal is the primary management objective. But if enhanced renovation is desired, the residence time is important. Many of the assimilative processes in wetlands depend on slow moving, sheet flow conditions. Typically, residence times in the range of 7-14 days are sought for enhanced treatment.

It is a good practice to calculate residence times for different hydraulic conditions, from low flows to flood flows. This might serve as an indicator of when flows might be increased (e.g., during low flow, long residence conditions) and when flows might be decreased due to shorter than acceptable residence times (e.g., high or stormwater flow conditions). See Section 9.5 for methods to estimate residence times.

Estimation of Sensitivity to Hydraulic Fluctuations. Estimating wetland sensitivity to hydraulic variables is difficult based on the currently available data. The importance of flow and hydroperiod on vegetation species, wildlife habitat and reproductive cycles has been discussed. Since the effects of hydraulic fluctuations on specific wetlands is difficult to generalize, site-specific estimates will be necessary in most cases. The interrelationships between hydrology, geomorphology, water quality and ecology also make the task of assessing sensitivity more difficult. Table 8-3 provides some general indications of sensitivity by wetland type. Although general, these wetland sensitivities should be considered in establishing hydraulic loading limits.

Hydrologic Interconnections. The classification of a system as hydrologically open or isolated is important. Open systems are typically less sensitive to hydraulic loadings than isolated systems, since the latter have greater flushing ability. Additionally, groundwater connections (i.e., groundwater recharge or discharge) may differ between hydrologically open and isolated systems. Therefore, a determination of whether the wetland is hydrologically isolated or connected should be conducted. Table 5-5 summarizes observed hydraulic loading by hydrologic type. Note that these are observed and not recommended rates. For some of the rates observed, detrimental impacts have resulted. The maximum loading rates to hydrologically isolated systems are less than for connected systems. This is due largely to the restricted outflows and flushing in isolated systems. Site-specific assessments will be necessary regardless of a wetlands hydrologic classification to assess sensitivity to hydraulic loading.

Table 5-5. Range of Observed Hydraulic Loading Rates (in/week) for Different Wetland Types*

Open Systems	Isolated Systems
Bottomland hardwoods 0.04 - 3.8	Bog/Pocosin 0.04 - 1.02
Cypress strands 0.9 - 5.1	Cypress dome 1.0 - 3.0
Marsh 0.01 - 3.8	

*These are observed, not recommended, ranges. A rate not exceeding 1 in/wk is recommended unless a higher rate can be shown not to degrade the wetland or exceed water quality standards.

When developing acceptable hydraulic loading rates, all inflows and outflows of the wetland system (i.e., the water budget) should be delineated. The inflow/outflow rates of precipitation, evapotranspiration, surface water and groundwater can vary daily, weekly and seasonally. The hydraulic loading rate of wastewater must adapt to these variations. It is recommended that weekly or monthly averages be used as guidelines for design. Operation rates can be refined in response to actual site conditions. Variable hydraulic loadings based on natural wet and dry periods should be incorporated into design.

5.3.2 Nutrient Loadings

One of the valuable functions of wetlands is their uptake and release of phosphorus, nitrogen, sulfur and carbon. Most wetlands can assimilate the nutrient levels present in secondary treated wastewater with little impact other than increased growth of vegetation. Nutrient loading rates are important for wetland systems designed to provide removal of nutrients (nitrogen and phosphorus) from wastewater. In these cases, the nutrient loading rate is related directly to the wetlands' adsorption abilities. Nutrient loading rates must be developed in connection with hydraulic loadings so that residence times are adequate for nutrient removal mechanisms. Table 5-6 lists some nutrient loadings applied to various wetland systems and the resulting removal efficiencies.

Ultimately, nutrient loading limits should be based on the nutrient sensitivity of the wetland and downstream waters as reflected by water quality standards criteria. Typically, standards criteria are not established for nutrients in wetlands.

Table 5-6. Removal of N and P from Wastewater[a] and Fertilizer Applied to Natural Wetlands

Types of Wetland	Location	Size (ha)	Years Nutrients were Applied	Nutrient Loading		Nutrient Removal	
				Total P (g/m^2/y)	Total N	Total P (%)	Total N
1) Shrub-sedge fen	Michigan	1[b]	1[c]	1.7	1.9[d]	95	96[d]
2) Forest-shrub fen	Michigan	18.2	1[e]	0.9	1.5[d]	91	75[d]
			2[f]	2.6	6.5[d]	88	80[d]
			3[g]	1.7	9.3[d]	72	80[d]
			4[h]	1.8	6.2[d]	64	77[d]
			5[h]	1.7[h]	9.3[h,d]	65[h]	75[h,d]
3) Blanket bog	Ireland	-	1	5.0	7.4[d]	96	82[d]
			2	13.1	15.4[d]	72	87[d]
			3	8.1	10.3[d]	43	68[d]
4) Hardwood swamp	Florida	204	20	0.9	-	87	-
5) Cattail marsh	Wisconsin	156	55	15.2	-	32	-
6) Cattail marsh	Massachusetts	19.4	69	7.1	53.6	47	31
7) Cattail	Massachusetts	2.4	69	63.6	428	20	1
8) Deepwater marsh	Ontario	162	55	11.6	78.6	58[j]	41[j]
9) *Glyceria* marsh	Ontario	20	55	77	404	24[j]	38[j]
10) Cypress dome	Florida	1.0	4	17.2	-	41[k]	-

[a] Secondary effluent

[b] Area affected by study, entire wetland is 710 ha

[c] May - September

[d] Inorganic N only, organic N not measured

[e] August - October

[f] March - November

[g] April - November

[h] June - November

[i] Chemical fertilizers, not wastewater, applied

[j] Wastewater applied year-round, but percent removal measured during the growing season only. Percent removal would likely have been much less if calculated on a year-round basis.

[k] Infiltration accounts for 50% (8.6 g/m^2) of output while runoff accounts for 9.3% of output.

Conversion factors: 1 ha = 2.47 acres; 1 g/m^2 = 8.91 lb/acre.

Source: Adapted from Richardson & Nichols 1985.

Therefore, on-site assessments may be necessary to establish nutrient limits. Also, generalized nutrient loading information is of limited value. The main purpose of Table 5-6 is to show a range of nutrient applications and nutrient removal potentials. This may be helpful as a general guide to reasonable loading and performance criteria.

Effluent limits based on these criteria depend on the hydraulic loading, form of nutrients, nutrient assimilative or removal mechanisms and which nutrient is limiting. Wetland size and residence time also affect acceptable nutrient loading levels. Nitrogen is generally more effectively removed than phosphorus.

5.3.3 Organic Loadings

Wetland systems effectively assimilate organic loads from wastewater, typically measured in the form of BOD_5 (EPA 1983b, Stowell et al. 1980). Removal capability depends on vegetation type, growth patterns, and temperatures. Aquatic systems can be overloaded with organic material, especially in winter months when microbial activity is slowed.

Much of the documentation concerning BOD loadings is for created aquatic systems. Created systems' loading rates range from 20 to 100 kg/ha.day (18 to 88 lbs/ac.day). Middlebrooks (1980) suggests using organic loading rates of 30 kg/ha.day (26 lbs/ac.day) or less to prevent odor production; however, the applicability of this information to natural wetland systems may be limited. The organic loading to most existing natural wetland-wastewater systems is typically based on secondary treated effluent quality, or 30 mg/l of BOD_5. A 0.25 mgd (million gallons per day) discharge with an effluent containing 30 mg/l (milligrams/liter) BOD would discharge 63 lbs. of BOD per day. Based on the above loading suggestions, about 2.5 "effective" acres would be necessary for such a discharge. Assuming 100 gallons per person per day, this would require about 1 acre per 1000 persons, which is significantly higher than the 60 persons per acre Nichols (1983) cited for 50 percent nutrient reduction. This indicates the need to address wastewater management objectives in the design process. It also shows that a loading rate based on one constituent is not the proper way to design a system. The person per acre figure given above also suggests a loading of over 20 inches per week, which would not be an acceptable hydraulic loading rate.

Dissolved oxygen (DO) levels are directly affected by organic nutrient and loadings. Increased organic loadings typically lead to lower dissolved oxygen levels. Natural background DO levels vary through the day, responding to the rate of photosynthesis, respiration, reaeration and to water temperature. Since some wetlands become periodically anoxic (very low DO levels), wetlands can have low DO levels without the addition of wastewater organics and nutrients. Wetland organisms have adapted to these widely fluctuating DO conditions. Organic loadings should not be large enough to overload the wetland, causing increased anoxic periods.

5.3.4 Metals/Toxins Loadings

Heavy metals and other toxins found in wastewater can have damaging effects on wetland systems. Richardson & Nichols (1985) found that the movement of heavy metals in the natural cycles of the wetland vegetation and sediments implies that wetlands are not final sinks for these metals. As a result, effluents with high metals concentrations such as would be introduced by industrial wastes should not be applied to wetland systems.

Little information is available on the level of toxicity of various metals that can be assimilated by wetlands. As a guide, Table 5-7 lists maximum concentrations of various heavy metals in irrigation water that have been recommended for protection of crops and those life forms that consume raw crops. For wetland vegetation, upper limits may or may not be lower than those indicated; little research has been conducted relating the stress caused by specific pollutants to the many types of wetland vegetation.

Due to the potential long-term, detrimental impacts from heavy metals, salts, biocides and other toxins, wetlands discharges should be limited primarily to domestic effluent. An applicant for a discharge with an industrial component should demonstrate that the effluent is non-toxic through the use of bioassays, pilot studies or available literature. An assessment of long-term loadings and bioaccumulation should also be conducted before loading limits can be established.

5.3.5 pH Levels

Most wetland waters in the Southeast are naturally acidic (pH less than 7.0). Wetland types that have minimal buffering influences tend to be even more acidic due to the formation of organic acids and the breakdown of organic compounds in the water. This is true of Sphagnum-type bogs, pocosins, cypress domes and others.

Generally, the pH of treated wastewater is around the neutral level (6.0 to 8.0). The application of wastewater with neutral pH levels is acceptable for most wetlands. However, discharges to wetlands that are pH sensitive may require modifications to the pH of wastewater prior to discharging. Site-specific decisions on pH effluent levels should be made.

Table 5-7. Recommended Maximum Concentrations for Trace Metals in Reclaimed Water Used for Irrigation.

Constituent	Long-Term Use[a] (mg/l)	Short-Term Use[b] (mg/l)	Remarks	Typical Concentrations in Secondar Treated Municipal Wastewater (mg/l)
Aluminum	5.0	20.0	Can cause nonproductivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.	-
Arsenic	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.	0.002
Beryllium	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.	-
Boron	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/l in nutrient solutions. Toxic to many sensitive plants (e.g., citrus plants) at 1 mg/.	-
Cadmium	0.01	0.05	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solution. Conservative limits recommended.	0.01
Chromium	0.1	1.0	Not generally recognized as essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.	0.09
Cobalt	0.05	5.0	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.	-
Copper	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solution.	0.05
Fluoride	1.0	15.0	Inactivated by neutral and alkaline soils.	-
Iron	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.	-
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations.	0.02 to 0.03
Lithium	2.5	2.5	Tolerated by most crops at up to 5 mg/l; mobile in soil. Toxic to citrus at low doses--recommended limit is 0.075 mg/l.	-
Manganese	0.2	10.0	Toxic to a number of crops at a few-tenths to a few mg/l in acid soils.	0.05
Molybdenum	0.01	0.05	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.	-
Nickel	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.	0.2
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of added selenium.	-
Tin, Tungsten and Titanium	-	-	Effectively excluded by plants; specific tolerance levels unknown.	-
Vanadium	0.1	1.0	Toxic to many plants at relatively low concentrations.	-
Zinc	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.	0.3

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[a] For water used continuously on all soils.

[b] For water used for a period of up to 20 years on fine-textured neutral or alkaline soils.

[c] Depends upon extent of disinfection.

Sources: U.S. EPA (1980) and data from North Carolina and California.

5.4 EFFLUENT LIMITS

The determination of effluent limitations for wastewater discharges to wetlands is complicated by the lack of appropriate models, the typical tool used for most receiving waters, and the difficulty in extrapolating from biological assessments to quantitative loading values. It is also important to establish the relationship between parameters that fundamentally affect water quality in wetlands, yet are not related to the level of treatment; hydraulic loading, velocity, water depth and hydroperiod are such parameters.

Several elements are necessary to assess effluent limits for wetlands wastewater discharges, including:

1) Review of existing water quality standards criteria and their applicability to wetlands
2) Downstream water quality requirements
3) Review of discharge loading limits and their apparent effects to similar wetland types
4) Site-specific classification of a wetland as effluent-limited or water-quality limited, including assessment of cumulative effects
5) Determination of effluent limitations including the use of mathematical models or on-site assessments.

Elements 4 and 5, those actually involved in establishing effluent limitations, will be discussed in the following sections. Table 5-8 indicates the current state policies and procedures for determining effluent limitations in wetlands.

Water quality criteria are established to protect the identified uses of waters of the U.S. Effluent limitations are intended to protect receiving waters and maintain standards criteria by preventing their assimilative capacities from being exceeded. For wetlands, the initial step in assessing effluent limitations is evaluating the applicability of existing criteria to wetlands. If generic or site-specific standards have been developed for the wetland, the determination of effluent limitations is simplified. If such standards are not available, a site-specific assessment likely will be needed. Information gained from studies of discharge loading rates to wetlands also might provide guidance in establishing effluent limits.

Table 5-8. Current State Policies and Procedures Affecting Establishment of Effluent Limitations

State	Methods Used to Develop Effluent Limits for Wetland Discharges	Existing Policies on Wetland Discharges
AL	D.O. model	No specific policy, best professional judgement used.
FL	Biological assessment for advanced treatment cases	Wetland discharges allowed under experimental projects. Recent legislation requires assessing use of wetlands for wastewater treatment.
GA	D.O. model plus biological assessment for advanced treatment cases	A minimum of secondary treatment for POTWs and BAT for nonmunicipal discharges.
KY	-	No current policy, no wetland discharges.
MS	-	Secondary treatment generally required. Existing criteria modified based on background conditions and best professional judgment.
NC	DO model or qualitative analyses	Natural background levels not lowered by discharge.
SC	Mathematical model	All reasonable alternatives considered before swamp discharge allowed. A minimum of secondary treatment for POTWs and BAT for nonmunicipal discharges.
TN	D.O. model modified by by best professional judgement	No specific policy, although WQS criteria modifications for natural conditions are employed.

Source: CTA Environmental, Inc. 1984.

5.4.1 Classification of Wetlands as Effluent- or Water Quality-Limited

In determining the classification of the wetland as effluent-limited or water quality-limited, several factors are involved:

1) Should the wetland be given the same designation as the adjoining stream segment?
2) Under what conditions is a wetland effluent limited?
3) Under what conditions is a wetland water quality limited?

This determination is important since the process is simplified if the wetland is classified as effluent-limited. If the wetland is effluent-limited, effluent limitations are established by regulatory guidelines as technology based. This means that the effluent characteristics are based on the typical effluent qualities associated with secondary treatment. The questions and complexities concerning effluent limitations for wetlands discharges are simplified if a wetland is designated effluent-limited.

Should wetlands be designated the same as the adjoining stream segment (for interconnected wetlands)? A general practice to do so may be inappropriate. Due to a wetland's assimilative capacity, water discharging from a wetland may not reflect the pollutant sources entering a wetland. Likewise, pollutant sources entering an adjacent stream may have little or no impact on the wetland. For these reasons, it appears that a wetland should, in most cases, be classified on a site-specific basis, independent of the adjoining stream segment classification.

The main issue is defining the conditions which prescribe a wetland as effluent- or water quality-limited. Ideally, most states make this determination based on a site-specific assessment of the receiving water at the time a discharge is proposed. If more than one facility discharges to the receiving waters, the cumulative effects of the discharges influence the stream classification. At a low application rate, a wetland might be effluent-limited; whereas, at some higher application rate, it would be classified water-quality limited.

The problem encountered when classifying the wetland is determining the assimilative capacity. For most free-flowing streams, this is accomplished through the use of mathematical models to simulate dissolved oxygen levels. The problem in wetlands is twofold. First, few of the models used for stream assessments can be applied to wetlands. Second, dissolved oxygen may not be the best indicator of assimilative capacity in wetlands (or protection of wetland functions and values).

One approach to defining effluent- and water quality-limited segments is conducting a site-survey to evaluate the effects of a discharge. The following questions should be considered when evaluating a wetlands' assimilative capacity.

1) Is the wetland receiving significant point or nonpoint sources (e.g., runoff from impervious surfaces or construction, other wastewater discharges)?
2) Are downstream waters sensitive to nutrients (wetlands assimilate nutrients, but some nutrients may be flushed from the wetland)?
3) Is the wetland itself highly sensitive to water or nutrient additions?
4) Does the wetland currently show signs of stress (including algal blooms, dying or dead trees, etc.)?
5) Will protected uses be impaired or existing uses be degraded by a secondary discharge?

These questions should be answered in association with the narrative, and perhaps numeric, standards criteria established for the wetland. If the response to the questions is no, the wetland could be designated as effluent-limited, and secondary treatment would be appropriate. If one or more responses are yes, the classification might be water quality-limited, with specific attention given to the parameters which would not comply with criteria (e.g., nutrients). The situation could arise that a wetland was considered effluent limited for water quality parameters affected by treatment processes, but not for other parameters such as hydraulic loading. These and other issues pertaining to the determination of effluent limitations are discussed in the following sections.

5.4.2 Determination of Effluent Limitations for Effluent-Limited Wetlands

By definition, secondary treatment levels are sufficient to meet water quality standards criteria in effluent-limited segments. If secondary treatment was not sufficient, the segment would be classified water quality-limited. For an effluent-limited segment, then, the effluent limitations are typically those concentrations or loadings that can be obtained from secondary treatment; e.g., BOD and suspended solids concentrations of 30 mg/l for certain treatment processes. For a free-flowing stream nothing further would need to be addressed. For wetlands, however, other parameters may need to be considered.

Whether or not hydraulic loading, hydroperiod or biological conditions are defined by standards criteria for wetlands, a wetland could be designated effluent-limited relative to conventional water chemistry parameters. However, these three additional parameters may have a fundamental influence on the water quality and long-term capability of using the wetland for wastewater management. As a result, some minimum guidelines should be established for these parameters by the NPDES process.

If standards criteria are modified to include such parameters as has been suggested, then a discharge needing to limit its hydraulic loading might be considered water quality-limited for that reason; that is, criteria would not be met by secondary treatment alone. The mechanism by which such parameters are controlled is not as important as recognizing the current limitations which exist in applying effluent- and water quality-limited terminology to wetlands.

5.4.3 Determination of Effluent Limitations for Water Quality-Limited Wetlands

Unlike effluent-limited segments, site-specific effluent limitations must be established for water quality-limited segments. The methods currently used by regulatory agencies to derive effluent limitations include:

- Mathematical modeling
- On-site assessments.

If water quality-limited wetlands are to be considered for wastewater discharges, techniques must be employed that assess wetlands discharges thoroughly and that lead to effluent limitations which accurately portray the wetlands assimilative capacity. Effluent limitations should also reflect the antidegradation policies and standards criteria designed to protect wetlands functions, values and uses. In addition, the cumulative effects of all potential point and non-point pollutant sources and wetland impacts must be considered in any assessment, modeling or evaluation method.

The potentially limiting approach of using dissolved oxygen levels for assessing assimilative capacity and assigning effluent limitations also applies to water quality-limited wetlands. Other parameters should be used in the determination regardless of being specifically addressed by water quality standards.

In a water quality-limited situation where downstream water quality may be a concern, effluent limitations for certain parameters could be tied to the standards criteria of the adjacent water body or stream segment, as long as standards criteria in the wetland still are met. This may provide impetus to use qualitative criteria for wetlands, particularly during dry periods, to assure wetlands protection.

The two primary reasons a segment might be classified as water quality limited are:

1) Sensitivity to pollutants, either inherently or due to other pollutant sources
2) Sensitivity of downstream waters.

The key is determining for which parameters the segment is water quality-limited. It may be water quality-limited relative to all the conventional wastewater characteristics: BOD, suspended solids, pH, water temperature, fecal coliforms and nutrients. The segment may only be limited in relation to one or two parameters; in such cases secondary treatment is sufficient for the other constituents, and more stringent limits are applied selectively.

Mathematical Modeling. Many types of mathematical models are available for predicting the effects on a system from internal or external changes. Models can be general in nature or site-specific. Three types of aquatic system models exist (Mitsch 1983):

o Watershed models
o Transport-fate models
o Ecosystem effect models.

Watershed models address stream flows and watershed runoff. The quality of water in terms of sediments nutrients or pesticides can be predicted by these models. An example is the Storm Water Management Model (SWMM) developed by EPA. Transport-fate models predict the changes in water quality at points downstream from a pollutant source or at various segments of open water bodies. Ecosystem-effects models predict the effects of pollutants on a biological component of the overall ecosystem.

Further, some models provide information on wetland processes that are not intended to assess assimilative capacity. For reasons stated above, the use of dissolved oxygen as a measure of assimilative capacity upon which effluent limitations are based, has significant limitations in its application to some wetlands. Nonetheless, the evaluation of assimilative capacity in some wetlands with more defined channels and with standing or flowing water throughout the year might be assisted by modeling applications.

The most commonly used water quality models for determining wasteload allocations and effluent limits are of the transport-fate type. These models predict the dissolved oxygen (DO) sag in water bodies resulting from the introduction of organic loadings (BOD). General models such as DOSAG, Streeter-Phelps, and Qual I have been utilized. Table 5-9 identifies the current modeling usage of Region IV states. These transport-fate models are most applicable to one-dimensional water bodies and are not appropriate for most wetland systems. Wetlands tend to be ever changing in flow conditions, biochemical conditions and boundary limits. Most existing models do not account for these types of changes. The use of an existing general water quality model for directly developing effluent-limits for wetland-discharges is not recommended. Models may give some guidance, however.

Site-specific models have been developed to determine the effects of wastewater application on specific wetland systems. The wetland geomorphology, hydrology, ecology and water quality must be identified adequately to produce accurate results. The model should emphasize those aspects of the wetland system that are of major concern. The use of site-specific models for determining effluent limits is possible and may be useful in special cases, such as when significant debate over wastewater impacts warrants the cost of developing a site-specific model. These site-specific models result in numerical predictions. Caution should be taken when using these numbers because they are merely predictions. Common sense and professional evaluation must be applied along with model results to establish reasonable and environmentally protective effluent criteria.

Table 5-9. Current Use of Aquatic System Models for Establishing Effluent Limits in Region IV States

AL	No wetlands modeling to establish effluent limits at present. Two-dimensional "link-node" model being developed for future use.
FL	No wetland modeling to establish effluent limits.
GA	Modified version of DOSAG for unbranched river segments, has not been used for wetlands.
KY	Broadbased dissolved oxygen model, that has not been used to date.
MS	AWFRESH for streams; use professional judgement for bayous.
NC	Limits determined in unmodelable systems based on a site visit, field study and/or best professional judgement.
SC	DOSAG II used for swamps with definable channel geometry and flow patterns.
TN	A modified form of Streeter-Phelps model is used for streams and flow-through type wetlands. A lake model is used for wetlands where little or no flow exists.

Source: 'CTA Environmental, Inc. 1984.

Many mathematical models have been prepared specifically for freshwater wetlands. Table 5-10 lists general wetland types and the degree to which simulation models have been applied to them. These models are usually site-specific. Although modeling may not currently have great applicability for determining effluent limits, certain models may be helpful for planning and design. Ecosystem and water management simulation models offer benefits for system and impact analysis.

Some wetland models have been developed by utilizing and adapting existing general models such as SWMM (Hopkinson and Day 1980). Mitsch et al. (1982), provide an overview of wetland models. Table 5-11 describes wetland simulation model types. Only a few of these models directly address the effects of wastewater application on the specific wetland. A hydrodynamic transport model, as described in Table 5-11, could be used to provide guidance in establishing wetland effluent limits. This model type has not been applied as such, however, and would require training concerning data requirements, calibration and application.

Table 5-10. Major Types of Freshwater Wetlands in North America and Degree to Which Simulation Models are Available.

	Modeling Effort		
Type of Wetland	High	Moderate	Low or None
Forested Swamps	X		
Bottomland Hardwood Forest			X
Marshes and Shallow Ponds			
Emergent Vegetation	X		
Floating Vegetation		X	
Bogs and Fens			X
Agricultural Wetlands			X

Source: Mitsch et al. 1982.

Table 5-11. Wetland Simulation Model Types

Model Type	Description	Example of Model	
		Simulation	Conceptual
1. Energy/nutrient ecosystem	-Related to energy, nutrients or other materials cycling, non-spatial	Mitsch (1976)	Kuenzler et al. (1980)
2. Hydrology			
a. Ecosystem	-Water budget description of a wetland without regard to connections with external water bodies	Huff & Young (1980)	-
b. Regional	-Considers water budget for larger watershed or regional areas	Brown (1978); Littlejohn (1977)	Rykiel (1977)
c. Hydrodynamic transport	-Describe hydrology and spatial pollutant transport	Hopkinson & Day (1980b)	-
	-Hydrology with wastewater inputs for a fen	Hammer and Kadlec (1985)	-
3. Spatial ecosystem	-A combination of ecosystem modeling concerns with spatial transport models	Parker & Kadlec (1974)	-
4. Tree growth	-Simulates the growth of trees	Phipps (1979)	Mitsch and Ewel (1979)
5. Process	-Describes individual processes occurring within the wetland such as photosynthesis	Miller et al (1976)	
	-Nutrient dynamics	Kadlec and Hammer (1985)	

Source: Adapted from Mitsch et al. 1982.

On-Site Assessments. All eight Region IV states conduct on-site assessments as part of permitting discharges to wetlands. The components of these assessments are project-dependent. Based on a survey of state practices, no formal guidelines seem to exist for these assessments. On-site assessments are used not only to classify wetlands (effluent- or water quality-limited), but also as a basis for professional judgement in determining effluent limitations. Two important aspects of on-site assessments need to be addressed:

1) Guidelines to improve the reproducibility, consistency and thoroughness of on-site assessments
2) The translation of results from on-site assessments to effluent limitations.

To improve the reproducibility or consistency of results a standard approach to on-site assessments should be adopted. On-site assessments may be necessary to establish site-specific standards criteria, to designate the wetland as effluent- or water quality-limited and/or to establish effluent limitations. The approach adopted should meet the objectives of each. It is anticipated the state will conduct these analyses; whereas, the applicant will conduct site-screening and engineering planning analyses. Since similar data collection efforts may be required from these programs, the adoption of standard guidelines and approaches should improve the efficiency of data collection.

The characteristics of wetlands and their abilities to renovate wastewater are sometimes masked by the diurnal and seasonal changes in wetlands. These and other factors affecting data collection programs are discussed in Section 9.2. These considerations should be incorporated into the design and implementation of data collection efforts. The tiered approach presented in Chapters 3 and 4, to differentiate between the level of analyses required of discharges with different degrees of uncertainty, also applies here. The following elements should be assessed in relation to criteria discussed in Section 5.2, and the establishment of effluent limitations. The analyses to be conducted for Tier 2 discharges are indicated.

Geomorphology
- Type of wetland
- Watershed condition and development
- Soil characteristics (Tier 2)

Hydrology (see Section 9.5)
- Hydrologic interconnections
- Hydroperiod assessment (timing and degree of fluctuations)
- Flow patterns within wetland
- Presence of water line on trees or shrubs
- Recent flow conditions prior to assessment (high or low flow)

Water Quality

- Basic water chemistry (see Section 4.4)
- Nutrient cycling assessment (periods of uptake and release, if any) for nutrient sensitive wetlands or downstream waters (Tier 2)

Ecology

- Visible condition of the wetland
- Predominant vegetation
- Presence of floating vegetation
- Presence of protected species or habitats

Planning

- Inventory of other pollutant sources
- Potential impairment of uses resulting from a wastewater discharge
- Potential downstream impacts

The second important aspect of on-site assessments is how they can be translated to effluent limitations. This is particularly important for water quality-limited segments but may also be a consideration for effluent-limited segments when limitations are needed for parameters other than water chemistry.

If the wetland is sensitive to water chemistry changes either naturally (e.g., bogs to pH) or because of other pollutant sources, those parameters can be addressed specifically so that the effluent will not adversely affect the wetland. The same is true in situations where downstream waters may be nutrient sensitive. In these situations, however, the effluent limitations could be based on the criteria of the downstream water body. If nutrient removal is the objective, it may need to be achieved at the treatment plant. This may be true for many wetlands, which either are limited in their ability to retain a nutrient or release nutrients in the non-growing season. Some wetlands have similar characteristics to land application systems.

A hierarchical approach for translating on-site assessment results to effluent limits could include the following steps:

Step 1:
Review applicable water quality standards criteria for wetland and downstream waters

Step 2:
Begin effluent limit analysis by assuming standard secondary treatment levels for each constituent (e.g., 30 mg/l of BOD and suspended solids)

Step 3:
Based on wetland type and on-site assessment, evaluate sensitivity of wetlands and downstream waters to waste-

water additions, giving particular attention to flow, pH, BOD, suspended solids and nutrients. Assess sensitivity in conjunction with background conditions and potential wastewater additions.

Step 4:
Determine other pollutant sources to wetland, i.e., other point sources and nonpoint sources.

Step 5:
Calculate the percent of total wetland flow or volume of the proposed discharge. Compute for low water, normal and high water (stormwater runoff) conditions.

Step 6:
Using average flow or volume values, calculate loadings to wetland. Determine constituent concentrations in "effective" wetland area assuming no assimilation (i.e., resulting from dilution alone).

Step 7:
Apply a conservative removal percentage that reflects average assimilative capacity of wetland for the constituent of concern under normal flow regime. Assess impacts of low or high flows on residence time and assimilative processes; evaluate effects on instream conditions.

Step 8:
If other pollutant sources discharge to wetland, determine percentage of flows and constituent concentrations attributable to proposed discharge. Employ the total maximum daily load concept to determine acceptable loadings of proposed discharge.

Step 9:
Estimate contribution of point sources versus nonpoint sources on an annual basis, assuming secondary treatment levels for point sources. Evaluate the percent reduction in total point and nonpoint loadings on an annual basis if treatment greater than secondary is required for certain constituents. If reductions are not significant, nonpoint source abatement controls may need to be initiated before additional wastewater treatment can be justified.

Step 10:
If downstream waters are sensitive to a particular constituent, effluent limits can be based on meeting downstream criteria or instream performance criteria, provided wetlands standards also are met. It may be more practical relating a numeric loading to the downstream criteria.

Step 11:

If downstream waters require nutrient reduction, evaluate proposed loadings based solely on dilution versus downstream standards criteria. Then apply a conservative nutrient removal potential, if appropriate (i.e., based on an understanding of nutrient uptake, release and reduction processes).

Step 12:

Based on an assessment of all pollutant contributions, wetland and downstream water sensitivity and applicable water quality standards criteria, identify the constituent(s) which require additional treatment above secondary. If necessary, confirm the assessment by repeating steps 6 through 11 for the new constituent levels.

Expected removal efficiencies are difficult to project. It is suggested that information on removal processes and percentages discussed in this Handbook and the Phase I report (EPA 1983b) be reviewed and conservative estimates established. The determination of nonpoint source pollutant loadings also can be difficult to estimate. One approach to this task is to use generic nonpoint loading based on land use and soils. Some models are designed specifically for this purpose and have been calibrated for numerous land use types and community sizes. Typically, 208 projects developed this information, so it is likely that land use/nonpoint source relationships have been developed in your region that may be applicable.

The difficulty or ease in translating the results of on-site assessments to effluent limitations also is related to whether standards criteria are qualitative or quantitative. The task is more difficult when numeric standards criteria are involved, particularly when the wetland being considered has periods of no standing or flowing water. Seasonal criteria might be appropriate for such wetlands.

6.0 ENGINEERING PLANNING AND DESIGN

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6.0 ENGINEERING PLANNING AND DESIGN

Who should read this chapter? Mainly potential wetland discharge applicants and their engineers

What are some of the issues are addressed by this chapter?

- What parameters are important in planning/designing a wetlands-wastewater discharge?
- What options are available for preventing adverse environmental impacts of a wastewater discharge to a wetland?
- What have engineers and scientists learned from past and current wastewater discharges to wetlands?

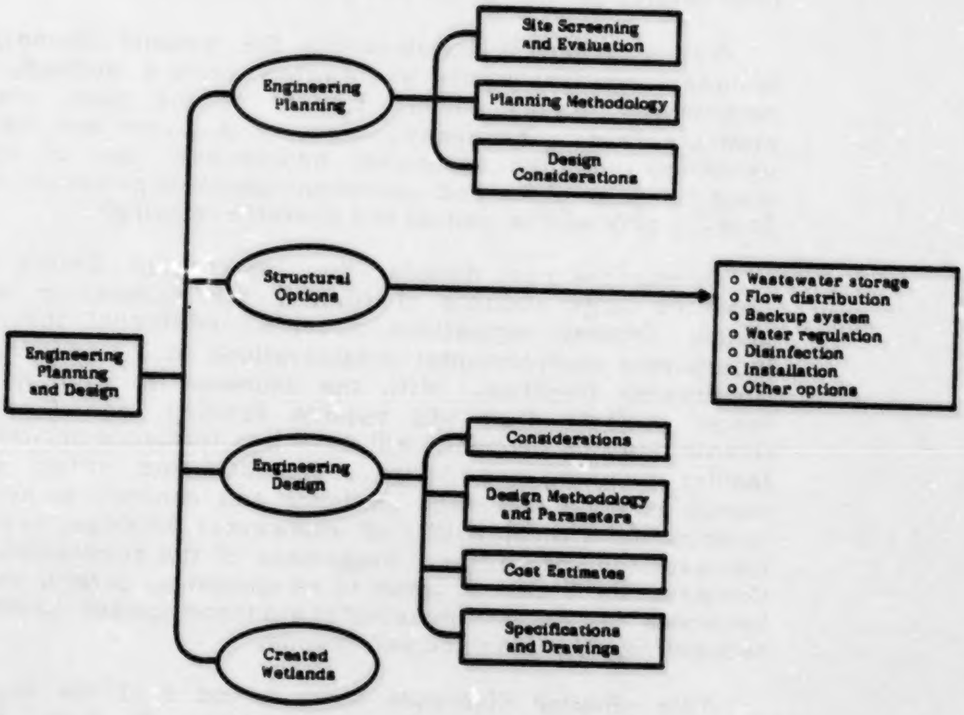

Engineering Planning and Design
Engineering Planning
Site Screening and Evaluation
Planning Methodology
Design Considerations
Structural Options
o Wastewater storage
o Flow distribution
o Backup system
o Water regulation
o Disinfection
o Installation
o Other options
Engineering Design
Considerations
Design Methodology and Parameters
Cost Estimates
Specifications and Drawings
Created Wetlands

Figure 6-1. Overview of Engineering Planning and Design.

6.1 RELATIONSHIP TO REGULATORY PROGRAMS

The engineering process includes planning; design; installation or construction; and operation, maintenance and monitoring programs. These four steps are sequential. Engineering activities, when conducted with a sensitivity toward environmental impacts, can help control and mitigate potential impacts. Both discharge permit requirements and the potential use of federal funds for wastewater facilities directly encourage environmentally sensitive engineering activities.

Each of the three regulatory programs, Water Quality Standards (WQS), NPDES Permitting and Construction Grants, influence engineering planning and design. The Water Quality Standards program ultimately will determine the level of treatment required prior to discharging to a wetland. The NPDES Permit program actually establishes the effluent limitations, but they are based integrally on the WQS program. The NPDES program probably will have the most influence on engineering planning and design through required application information, permit review and permit conditions.

Types of permit requirements for wetland discharges can include: locations where wastewater enters a wetland, outflow restrictions during certain time(s) of the year, monitoring elements (e.g., frequency, types of analyses and monitoring locations), quality assurance procedures, use of treatment plant by-pass pipes and operation-maintenance-repair elements (e.g., a procedures manual and operator training).

During the past decade, the Construction Grants program provided large amounts of funding for wastewater facilities; hence, federal regulations provided additional incentive to incorporate environmental considerations in the construction of wastewater facilities. With the decrease in funding and the fewer projects that will receive funding, the Construction Grants program probably will have less influence on wastewater facility planning and design. The WQS and NPDES programs should provide increased guidance and controls to assure the environmental acceptability of wastewater facilities, particularly for wetlands discharges. Regardless of the applicability of the Construction Grants program to an applicant, careful use of this handbook can provide meaningful guidance toward meeting institutional requirements and safeguards.

This chapter discusses Steps 1 and 2 of the engineering process: engineering planning and design. Chapter 7 discusses the engineering aspects of project implementation: construction, operation and maintenance, and post-discharge monitoring. Figure 6-1 provides an overview of the engineering planning and design considerations.

6.2 ENGINEERING PLANNING

6.2.1 Relationship to Site Screening and Evaluation

Wetland-wastewater engineering planning involves defining the objectives and needs for a facility, assessing key engineering questions and determining alternative solutions. Engineering planning may lead to eliminating the possibility of a wetlands discharge; on the other hand, it may suggest the use of engineering design options not previously considered.

Two important criteria that should be assessed early in the planning phase are distance of the community/treatment plant to the wetland and the area of wetland needed for wastewater management use as portrayed in Figure 6-2. These and other preliminary site screening concerns are addressed in Chapter 4. Refined estimates of these factors must be obtained in the engineering planning stage. Excessive distance in conjunction with pumping costs (if needed) and/or the need for a larger wetland area than is available can eliminate the wetlands discharge option.

Many components of engineering planning involving site evaluations, alternative systems evaluation and preliminary cost-effectiveness analyses have been discussed previously in Chapter 4. The information gathered through the **Chapter 4 User's Guide** should be the basis for engineering planning and design.

6.2.2 Planning Methodology

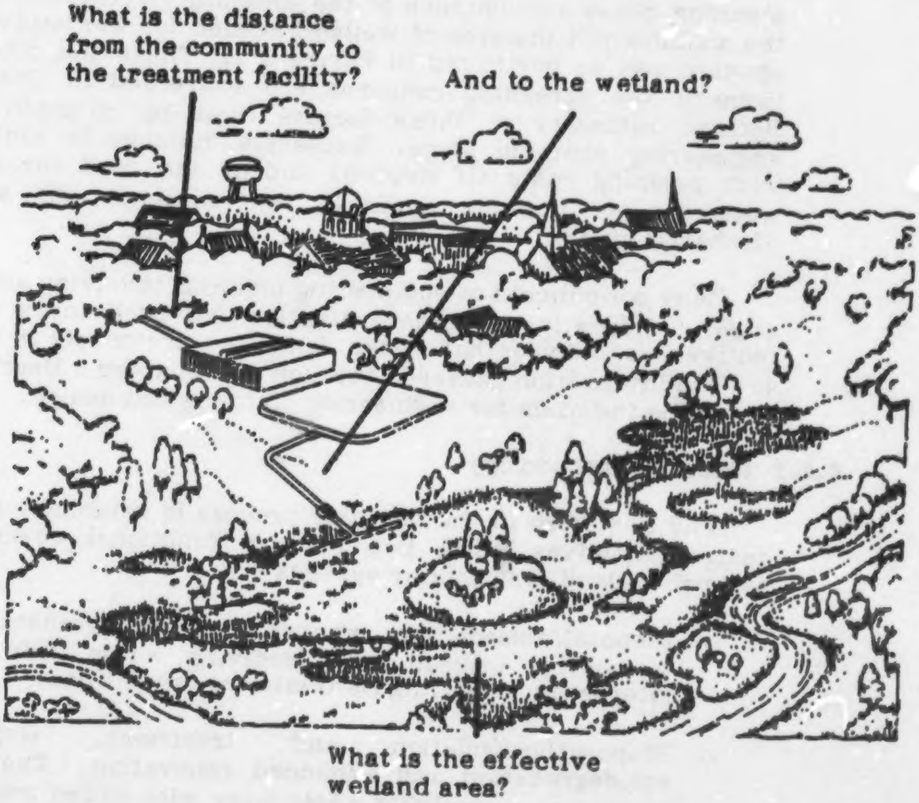
The first step in the planning process is establishing system design objectives. The two primary functional objectives of natural wetland-wastewater systems are:

- Disposal/assimilation, emphasizing antidegradation. The wetland is utilized as a receiving water body without interest in optimizing its treatment capabilities.
- Disposal/assimilation and treatment, emphasizing antidegradation and enhanced renovation. The wetland is used as a receiving water body with added emphasis on optimizing its treatment capabilities.

Optimizing wastewater assimilation within a wetland is a consideration, for example, when water quality standards (and associated wasteload allocations) for waters downstream of a wetland require advanced wastewater treatment.

Wetland antidegradation refers to maintaining a wetland's natural processes and preventing degradation by any wastewater or other type of pollutant input. Effects of wastewater on

Figure 6-2. Importance of wetland distance and area of wetland impacted.


What is the distance from the community to the treatment facility?
And to the wetland?
What is the effective wetland area?

Source: CTA Environmental, Inc. 1985.

the wetland itself, just like wastewater assimilation, are difficult to predict with a great deal of certainty. The same environmental fluctuations and seemingly random water movements complicate predictions of wetlands impacts and wastewater assimilation. Wetland preservation depends on the wetland's level of sensitivity and the quality and quantity of wastewater applied to it. Loading rates and pollutant limits for wastewater discharged to wetlands are discussed in Chapter 5.

Planning and designing a wetlands-wastewater system are integrally related to several wetland characteristics. Design parameters such as hydraulic loading depends on the size of the wetland and its sensitivity to hydrologic or water chemistry modifications. Therefore, wetland characteristics must be thoroughly evaluated, as described in Chapters 4 and 5, to assure adequate design and the incorporation of appropriate safeguards. System design is also affected by wetlands functions within the drainage basin, its other uses and values and the treatment required by water quality standards.

Other system objectives also should be considered when assessing the use of wetlands for wastewater management. These objectives include needs for:

1. Intermittent discharges
2. Seasonal discharges
3. Partial discharges.

Intermittent discharges are those necessary only at times during the year, e.g., if the capacity of percolation ponds was exceeded and another discharge mechanism was required. Seasonal discharges refer to those situations in which discharges may be necessary only for one or two seasons due to population fluxes. They could also refer to discharges which would be allowed only during certain seasons with associated hydrologic and water quality conditions. Partial discharges may be desirable in situations in which wetlands could receive part, but not all, of a facility's effluent due to wetland size or other restrictions. Under such circumstances, additional wastewater discharge alternatives would be necessary for the remainder of the effluent.

After all potential wastewater management alternatives have been defined, they should be compared and evaluated. The preferred alternative is selected based on community needs, financial costs, environmental impacts and implementation capability. Other alternative evaluation processes may include comparing alternative wetland sites or comparing engineering design options. Section 4.3 discusses the evaluation of alternatives.

Uncertainties concerning the effects of wastewater on wetlands performance should be incorporated into engineering planning and design. These are discussed in Section 8.4 and include:

- Long-term capacity for assimilation of wastewater (especially phosphorus)
- Effects of wetland flow patterns and changing boundaries on hydraulic design variables
- Ability to predict ecological changes from wastewater discharges. This is complicated by:
  - Variable and seasonal weather conditions
  - Other inflows to the system
  - Wastewater quality variations
  - Limited long-term information from existing wetland-wastewater systems

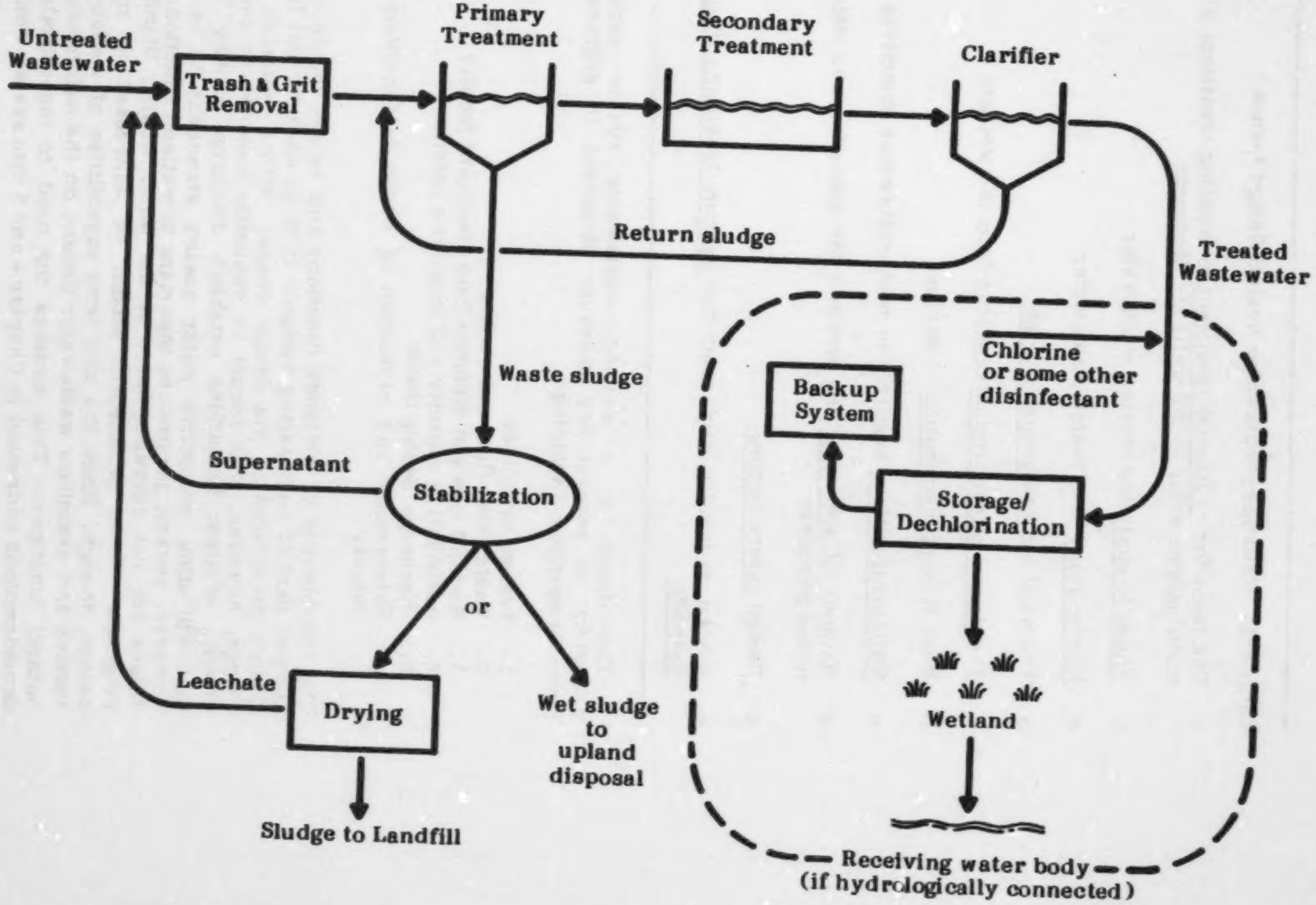
The following sections examine structural options and design considerations intended to address these and other concerns.

6.2.3 Engineering Design Considerations

Traditionally, wastewater facilities design has included plant siting, process design, construction staging, plant layout and facilities structures. These activities also must be conducted for a wetlands-wastewater system, since wetlands are only one part of the wastewater management system. The use of wetlands introduces potential benefits and risks, however, so design practices should incorporate some additional features. A typical wetland-wastewater management system is illustrated in Figure 6-3. The design concerns specifically addressing the use of wetlands will be discussed in this section; design of the primary and secondary treatment systems and sludge disposal methods are not included.

Table 6-1 lists the basic design concerns for a wetlands wastewater system. Addressing these design concerns involves analyzing the trade-offs among costs, environmental impacts, operating needs and implementing procedures. The method by which these issues can be addressed and used for system design is presented by the Chapter 6 User's Guide.

Once alternative discharge methods, locations and predischarge requirements are developed, the various facets of costs, impacts, operation and implementation should be considered carefully. Design decisions should be based on both cost-effectiveness analyses and qualitative judgements of available scientific and engineering information. Wetland scientists should be consulted while the alternatives are being evaluated and throughout the design stage.


Untreated Wastewater
Trash & Grit Removal
Primary Treatment
Secondary Treatment
Clarifier
Return sludge
Treated Wastewater
Waste sludge
Chlorine or some other disinfectant
Backup System
Storage/ Dechlorination
Supernatant
Stabilization
or
Leachate
Drying
Wet sludge to upland disposal
Wetland
Sludge to Landfill
Receiving water body (if hydrologically connected)

Source: CTA Environmental 1984.

Figure 6-3. Typical wetland-wastewater system.

Table 6-1. Wetlands-Wastewater System Design Issues

- The need for additional treatment or existing treatment plant modifications prior to the wetlands discharge
- Where to apply the treated wastewater
- How to apply the treated wastewater
- The need for wastewater storage
- The degree of renovation expected from the wetland
- What type of disinfection to employ
- Structural options available to meet wastewater objectives
- Methods of accessing the wetland for operation and maintenance purposes
- Design safety factors
- System reliability and need for backup treatment/disposal methods

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The design of a wetlands-wastewater system depends ultimately on several key elements discussed in engineering planning sections, including:

1. System objectives
2. Wastewater flow and quality
3. Wetland size and distance from treatment facility
4. Assimilative capacity and long-term potential
5. Discharge loading limits
6. Maintenance and protection of wetlands functions and values.

The maintenance of wetlands functions and values should be an integral part of engineering design. It is an element that is not always considered in the design phase. With a wetlands discharge, however, this should be explicitly included in design. Ideally, effluent limitations establish discharge loading limits that will allow protective water quality standards to be met. However, several parameters important to wetland functions and values are not currently part of the Water Quality Standards program. These parameters should be addressed in system design, though, since the long-term capabilities of wetlands to receive and assimilate wastewater depend on the maintenance of natural functions. This stresses the need to incorporate the considerations addressed in Chapter 4 and 5 into system design.

6.3 STRUCTURAL OPTIONS FOR WETLAND-WASTEWATER SYSTEMS

6.3.1 Purpose and Considerations

The wide variety of wetland types in Region IV and their varying hydrologic conditions requires a discriminating use of the engineering options presented in this chapter. It is recommended that the design of existing and potential wastewater discharges to wetlands considers all the benefits and costs of the technology presented here. Selection of the best engineering options requires the evaluation of the site-specific conditions for each wetland-wastewater management system.

The details of design and performance available for conventional wastewater management systems are not readily available nor time-tested for the wetlands wastewater systems. Nonetheless, information from existing natural and created wetlands-wastewater systems can be used for guidance, if properly applied. Chapters 5 and 8 present additional information gained from existing systems.

Most of the structural options encourage uniform distribution of wastewater flow throughout the wetland and describe modifications to wastewater treatment systems prior to the wetlands discharge. It is recommended that all options discussed in this section be considered by municipal wastewater planners prior to installing a new system or renovating an existing system.

Given the current limited ability to predict the extent of optimizing wastewater assimilation and the requirements for wetland protection, it might be appropriate when uncertainty is high (e.g., for large discharges to unstudied wetland systems) to test specific applications prior to full-scale implementation. Such tests could include bench-scale laboratory tests or field tests.

6.3.2 Structural Options

Structural options are intended to protect wetlands functions and values and, in selected cases, to enhance the wastewater renovation capability of a wetland. To meet these objectives, design and operation/maintenance guidelines are necessary. The latter are discussed in Chapter 7. Six structural design elements should be assessed for wetlands-wastewater systems. The selection of which options are most appropriate for a given wetland depends on such site-specific variables as wetland type and sensitivity, effluent quality, wetland size and system objectives.

Disinfection. Chlorination of wastewater prior to discharge into wetland areas raises concern over the possible production of chlorinated hydrocarbons. The production of these chlorine by-products could severely affect the health of wetland plants and animals, and alter the wetland ecosystem. Chlorinated hydrocarbons result from the reaction of chlorine residuals with organics in an acidic environment. Therefore, it is possible that hydrocarbons would be produced from chlorinated wastewater discharges into the highly organic and naturally acidic waters of wetland areas.

One option for reducing chlorine residuals or inhibiting production of chlorinated by-products is to dechlorinate the wastewater following chlorine additions. Dechlorination methods include:

- The addition of sodium metabisulfite or sulphur dioxide to the chlorinated wastewater
- Use of a detention pond to allow time for the natural dissipation of chlorine residuals
- Oxygen steps that help dissipate chlorine residual.

Another option is using alternative disinfection methods such as:

- Chlorine dioxide
- Ultraviolet light
- Ozone.

Throughout recent decades, chlorine has been utilized for disinfection at well over 95 percent of all wastewater treatment facilities. Hence, experience with these alternative methods is relatively limited in the United States, although their effectiveness in killing microorganisms in wastewater has been well proven. A cost analysis comparing the different disinfectants and associated O&M is highly recommended prior to design.

No disinfection is a third possibility. The cost savings and avoidance of chlorinated by-products associated with no disinfection, however, could be outweighed by the risks of pathogen transmission. Disinfection typically is considered part of secondary treatment and necessary to meet water quality standards. Where a bacterial water quality standards criterion does not exist or where the criterion can be achieved without disinfection, no disinfection may be feasible.

Wastewater Discharge/Distribution. Experience has shown that the more evenly wastewater is distributed over the surface area of the wetland, the greater the assimilation of flows, organics and nutrients (i.e., more complete mixing as opposed to plug flow from single pipe discharges). Uniform flow

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distribution should be achieved to protect the wetland from wastewater disposal and enhance renovation.

The options for flow distribution include:

- Multiple discharge locations
- Multi-port pipe
- Gated pipe
- Overland flow
- Spraying
- Single pipe
- Channel overflow.

Some of the advantages and disadvantages of these discharge methods are presented in Table 6-2. The use of multiple discharge points is recommended to enhance distribution of flow and maximize the effective area of the wetland. Having more than one discharge location within the wetland can also add flexibility to operation and maintenance. This option also helps maintain sheet flow and reduces the likelihood of creating effluent channels through the wetland.

Once the discharge locations are identified, the configuration of piping to distribute wastewater flow must be considered. Figure 6-4 illustrates several configurations. Critical concerns in choosing a distribution piping method include:

- Optimizing use of wetland area
- Reducing short circuiting through the wetland in the event of storms, high velocity flows or runoff
- Preventing damage to localized areas of the wetland if improperly treated wastes or a slug of industrial wastes enters the system.

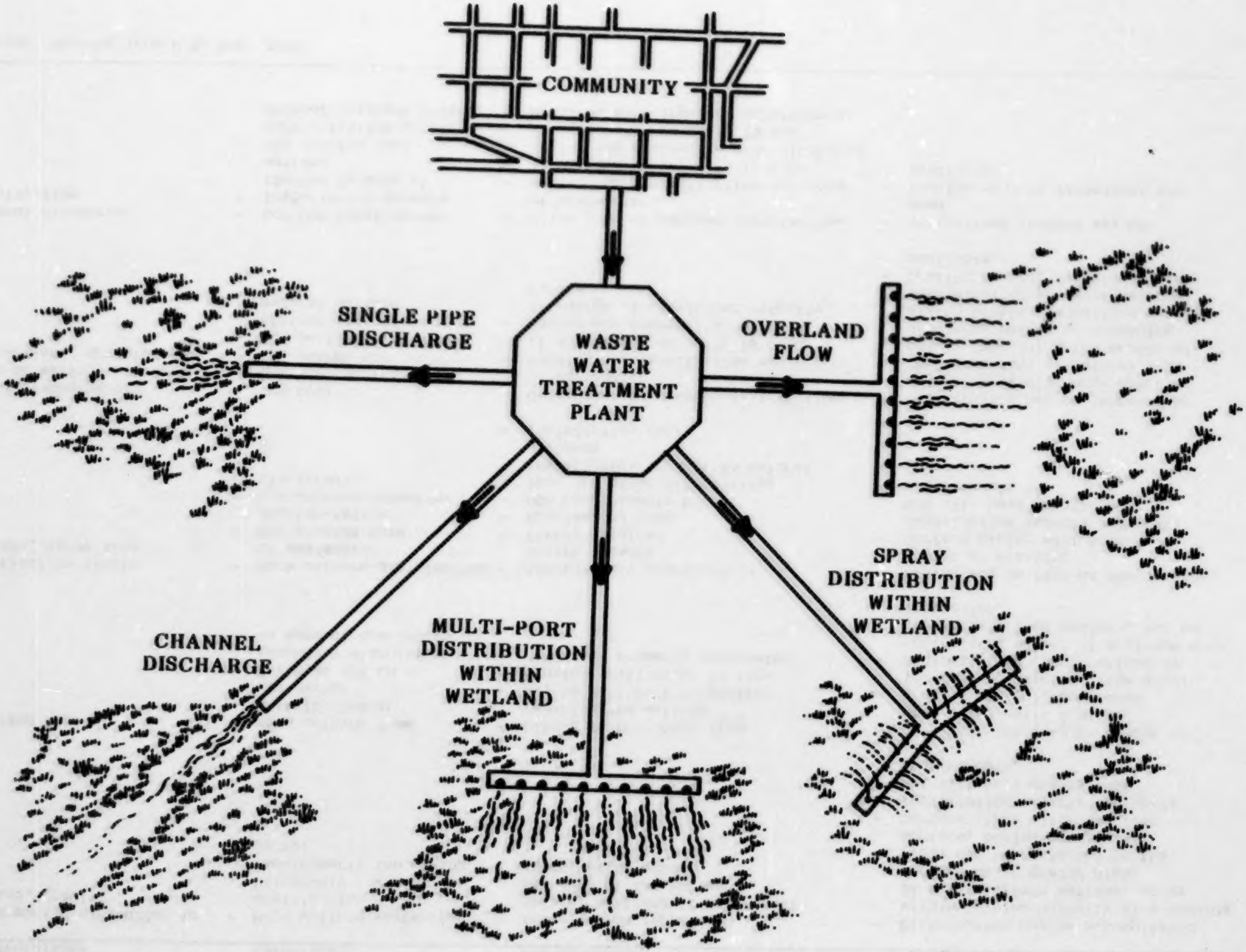
Multi-port piping or gated piping are also good methods for distributing flow throughout the wetland. Using these methods, flow is distributed along the length of the discharge pipe through the wetland. If hydraulic gradients are known, placement of pipes can direct flows to certain areas of the wetland.

Overland flow is an excellent method of discharging to a wetland. Besides serving as a means of flow distribution, such systems also can be designed to provide treatment. They can be designed as part of the treatment system in conjunction with a wetlands discharge. Figure 6-5 indicates the components of an overland flow system. Regardless of whether treatment is desired, the effluent enters the wetland evenly and without causing channelization. It does not provide the flexibility of multi-port discharges into the wetland; but in those cases where laying pipes in the wetland or from boardwalks may need to be avoided, or when additional treatment is desired, overland flow should be considered.

Table 6-2. Effluent Discharge Configurations

Effluent Application Configurations	Advantages	Disadvantages	Mitigating Measures
Multi-port distribution to wetland, gravity flow	- More uniform wastewater distribution - Relatively low O&M requirements (no moving parts)	- Installation impacts to natural wetlands if built past the edge of the wetland - Installation costs	- Distribution may be accomplished within by pipe outfalls at a variety of points within wetland, or by perforated or grated pipes - Pipes can be installed on the surface, buried or elevated - Surface pipes will have less installation impacts and costs but will have greater O&M requirements.
Overland Flow	- More uniform flow distribution of wastewater - Wetlands act as a secondary disposal area in some circumstances	- Little control over flow reaching the wetland - May be difficult to monitor - Erosion could occur if flow rates not properly calculated	- Potential increase in number of monitoring wells & sites - Erosion control techniques (contouring overland flow area) - Control storm runoff volume by controlling extent of drainage area of overland flow systems, and by vegetation.
Distribution within wetland, spray flow	- More uniform distribution of wastewater - May provide some dechlorination - Low erosion potential via spraying	- Aerosols may cause public health impacts - Energy required - Nozzles may clog - O&M requirements higher than for other alternatives - Installation impacts to natural wetlands - Installation costs	- Piping may be laid on the surface, buried or elevated - Surface piping will have fewer installation impacts and costs but will have greater O&M requirements
Point discharge at edge of wetland, or into the wetland, gravity flow	- Low cost - Low O&M requirements - Low energy use - Can be installed with minimal impacts to a natural wetland	- Often poor or unknown distribution of wastewater - Erosion & channelization may occur if wastewater velocity is high - Solids may accumulate near discharge if wastewater velocity is low	- Distribution may be improved by selection of discharge point to take advantage of natural flow paths, increasing the number of discharge points or enhancing mixing within the wetland by mechanical or physical devices - Erosion control techniques are available.
Channel discharge, gravity flow	- Low O&M requirements - Installation impacts limited to edge of wetland - May provide some dechlorination within channel (cascade effect)	- Often poor or unknown distribution of wastewater - Erosion or channelization may occur if wastewater velocity is high - Solids may accumulate near discharge if wastewater velocity is low - Requires more frequent maintenance	- Grass-lined channel may be used - Erosion control techniques are available.

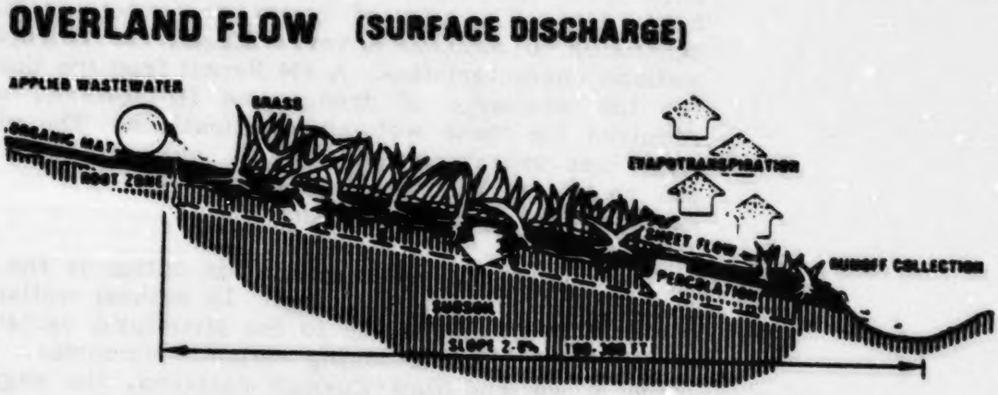
Source: Adapted from U.S. EPA 1980.


COMMUNITY
WASTE WATER TREATMENT PLANT
SINGLE PIPE DISCHARGE
OVERLAND FLOW
CHANNEL DISCHARGE
MULTI-PORT DISTRIBUTION WITHIN WETLAND
SPRAY DISTRIBUTION WITHIN WETLAND

Source: CTA Environmental, Inc. 1985.

Figure 6–4. Distribution methods for wetland–wastewater systems.

Figure 6-5. Overland Flow Treatment/Discharge System



Spraying is a discharge option often utilized for land application but relatively infrequently for wetlands. Nonetheless, it is a good mechanism for distributing the flow evenly and reducing channelization of flows. However, such a system may require additional piping and O&M. Also, spraying could impact vegetation and wildlife habitat more than ground spreading techniques.

Single pipe or direct channel flows have been used most often by existing wetlands dischargers. They are probably the least desirable due to their channelizing effects and short-circuiting of flows through the wetland. They also cause the greatest impact to the immediate vicinity of the discharge.

The design of discharge structures also should be based on the hydraulic loading considerations discussed in previous chapters. Knowledge of **hydraulic loading, timing, velocity, residence time** and **water depth** requirements for the wetland should be a major determinant in the selection and design of discharge structures, as well as water regulation structures. Section 5.4 discusses the importance of these hydraulic variables to discharge loading criteria. Section 9.5 presents potential methods for estimating these hydraulic and hydrologic variables.

Water Regulation. Regulated water flow into and out of the wetland can improve the use of a wetland system as a treatment method. Water regulation options include the use of 1) berms, levees and wiers, 2) multiple cells and 3) vegetation. The use of berms, levees and wiers is suitable in some situations, but often it leads to changes that could impact significantly the wetland. They typically are used in created systems to control water depth, retention time and flow patterns. However, berms (e.g., Cannon Beach, Oregon) and wiers (Reedy Creek, Florida) have been used for some natural systems to provide water regulation. The use of berms or levees should be carefully controlled to minimize adverse impacts on hydroperiod and other wetland characteristics. A 404 Permit from the Corps of Engineers for the discharge of dredge and fill material would likely be required for these wetland modifications. The use of wiers has much less impact on the wetland, since typically the structures are placed on the wetland boundary and can be controlled more easily not to impact the wetland.

Another major water regulation option is the use of multiple "cells" or areas for discharge. In natural wetlands, "cells" are difficult to delineate due to the structural variation of wetlands and difficulty in determining wetland boundaries. With some knowledge of wetland flow-through patterns, the engineer should be able to define distinct flow areas, so that "cells" can be designated. This has been accomplished for a project utilizing wetlands in Oregon (Humphrey 1984). Having a minimum of two cells, or two distinct wetland systems, would be beneficial for wetland types that require a dry-down period in order to reseed. Also, multiple cells allow for a resting period to reduce the stress load on the wetland. If distribution system repairs are needed, the second cell can be used during repair times. Multiple cell design provides a safety factor for design uncertainties.

The design of more than one wetland cell and/or several discharge locations within the wetland provides the opportunity for intermittent operation. An intermittent operation requires a mechanism for alternating discharge locations. This can be done mechanically or manually. A storage pond or equalization basin is necessary as part of an intermittent operation. Intermittent application helps buffer the hydraulic and organic/nutrient stress on the wetland. Alternating flows can be on short term or longer term cycles, depending on the anticipated "resting" times for the specific wetland type. Chapter 7 provides more information on intermittent operation and Figure 7-4 portrays the use of multiple cells.

Flows also can be regulated in the wetland by using of natural vegetation. The presence of vegetation slows and distributes flows. When selecting discharge locations, it is recommended that sites within the wetland with clumps of dense and diverse types of vegetation be used. The vegetation also acts as a filter and increases the assimilative capacity of the wetland (Gearheart et al. 1983).

A combination of using water regulation options and/or backup systems can be important during times when dry or resting periods are essential to wetland processes or habitat values.

Backup System. Backup disposal systems become critical in areas where winter operation might limit the assimilative capacity of the wetland, when seasonal flow conditions might prevent a discharge or when long-term impacts are being detected. System backups include: 1) other wetland areas, 2) other receiving waters or 3) land application. In cases where long-term impacts have been documented, the use of other wetland areas might also be limiting, depending on the reason for the impacts.

The purpose of a backup system is to assure the wetland will be protected and its assimilative capacity will not be overloaded. Due to the uncertainties associated with wetlands discharges under some circumstances, backup systems or alternatives to the wetlands discharge could be developed as a contingency. This is particularly important when little is known about wastewater impacts to the wetland type being used or when wastewater flows exceed the generally adopted conservative loading rate of one inch/week.

Facilities Installation. The installation of distribution facilities and other structural elements should limit wetland disturbance during and after installation.

Above ground piping, for instance, has been used and is the preferred option for minimizing wetland disturbance. Piping can be suspended along boardwalks, walkways or adjacent to roadways. This method provides access to the distribution system as well.

Pipelines above the ground can be more costly, however, and are susceptible to storms, cold temperatures and other external effects. They also can cause wildlife impacts as well as affect the hydraulic gradient if not properly planned and designed.

Pipelines below ground are not easily monitored nor maintained and are susceptible to differential soil movement common in a wetland area. Environmental impacts from installation are less significant for above-ground pipelines. The specific site conditions must be assessed to determine the best method of piping installation.

Other Structural Options. Wetlands are often part of a greater system of waterways and drainage areas. In these cases, wetlands used as wastewater management systems are subject to other upstream or offsite inflows. These inflows may contain pollutants (sediments, herbicides, pesticides, organics) from agricultural, urban or silvicultural (tree harvesting) runoff. State regulatory agencies could help to control the quality of these inflows by enforcing the best management practices for agriculture, tree removal and urban runoff. A structural option available for minimizing the effects of inflow pollutants on the wetland-wastewater system is the construction of upstream retention ponds or sediment traps. These facilities would act as collection basins for sediments and other pollutants. Such modifications should not affect the natural hydrologic regime of the wetland. The use of wetlands for wastewater management should be evaluated and, if implemented, operated in relation to other existing or potential inflows of pollutants.

The inclusion of artificial substrate in natural wetland systems is a structural option specifically geared toward improving the treatment capabilities of the wetland. Usually the material is placed in the wetland to provide more surface area for microbial organisms which conduct waste assimilation. It may be a usable option for situations in which the wetland type is not diversely vegetated (previously degraded) and enhanced treatment is needed.

Structural options exist which are used to limit public access in a wetland to which wastewater is being discharged. Warning signs can be posted, fences erected or the wastewater discharge could be located far from residences and parks. The municipality may not have the authority to carry out the most effective options for limiting access, such as erecting a fence; however, in some situations it may be important to consider implementing some type of system to inhibit public access.

6.4 ENGINEERING DESIGN

6.4.1 Purpose and Considerations

The design phase involves consideration of the structural options discussed in Section 6.3, collection of additional site information (see Detailed Site Evaluation Section 4.4) and determination of loading criteria needed to meet the prescribed effluent limitations. Section 5.3 discusses loading criteria used for current wetland discharges and the development of site-specific loading rates.

Prior to the design stage, most limitations to utilizing the wetland should be eliminated. Any remaining limitations should be those that are mitigated easily. Design procedures result in detailed decisions concerning all aspects of the wetland-wastewater system. Contract drawings and written specifications concerning how to install the system also are results of the design effort.

Use of safety factors to ensure that all wastewater management objectives are met also is encouraged, such as additional capacity and more conservative design criteria (e.g., lower loading rates and longer detention times) than would otherwise be designed.

Other safety factors to be considered during engineering design could include the following:

- Storage facilities to provide storage capability for excessively wet periods, cold periods (if nutrient and metal uptake are significant and desired in the system)
- Nutrient removal at the treatment plant
- Buffer zone around the wastewater discharge
- System isolation
- Chlorination followed by dechlorination, or some other method of disinfection
- Monitoring of system discharge and receiving waters (surface and groundwater)
- Extra monitoring of wetland vegetation for 1) metal or toxin accumulation and 2) changes in natural vegetation
- In-wetland management, if needed (e.g., harvesting of wetland vegetation).

These measures can help assure that a wetland system is not overloaded, that wastewater is properly assimilated and that wetland functions are maintained. The costs of implementing safety factors need to be compared with the degree of site-specific uncertainties in order to assess the value of applying safety factors.

6.4.2 Detailed Design Parameters

Most design parameters will be related in some way to the structural options. As has been described, hydraulic variables are the major determinants for not only the structural options but also wetlands protection and assimilative capacity. Table 6-3 describes many of the design parameters that should be considered for wetlands-wastewater systems.

The detailed calculations of all design parameters important to wetlands-wastewater systems are not addressed by this Handbook. Reaction kinetics, sedimentation rates and other processes are the subjects of numerous publications. Several references (Tchobanoglous and Culp 1980, Hammer and Kadlec 1983, Heliotis 1982) discuss the calculation of wetland design parameters in detail. Since hydraulic and hydrologic variables are basic to any engineering planning and design process, and are often difficult to determine for wetlands, they are addressed more thoroughly by the Handbook. Chapter 4 introduces the importance of defining the water budget and hydroperiod for some wetlands receiving wastewater. Ultimately, this information is used as a basis for detailed engineering design if a wetlands-wastewater system is feasible and a NPDES discharge permit can be obtained.

Hydraulic and hydrologic variables will affect the design of wastewater storage and back-up systems based on the wastewater flow, effective size of the wetland, climatic conditions, soils conditions and assimilative capacity of the wetland. Wastewater storage needs could vary from hours to weeks. The design of wastewater distribution and water regulation systems are also directly affected by velocities, depth, area of inundation and residence time. These hydraulic and hydrologic variables directly influence assimilation processes such as sedimentation which are enhanced by sheet flow, low velocities and longer residence times. Likewise, this could affect the design and use of other structural options, e.g., floating substrate for microorganisms.

Hydraulic Loading and Velocity. Wastewater loading and velocity are important hydraulic variables. The rate of wastewater loading (WL), the flow per unit area, controls all other hydraulic parameters. It is simply calculated as:

$$\text{WL} = \frac{\text{Flow of wastewater (e.g., mgd)}}{\text{Effective area of wetland}} \text{ X unit conversions}$$

From this equation the calculation of inches per week is derived (see Chapter 4 User's Guide).

Velocity is important for several reasons. High velocities can lead to scour, whereas low velocities ~~can~~ lead to settling and

Table 6-3. Design Parameters for Various Types of Structural Options

Option Type	Design Parameters	Operation-Maintenance-Replacement Needs
Need for additional treatment at plant	- Maximum daily wastewater flows and quality	- Chemical addition (for phosphorus removal)
	- Wetland assimilative capacity for pollutant of concern (organics, nutrients and/or metals)	- Routine treatment process maintenance and repair
Wastewater Storage	- Daily and hourly variations in flow reaching the plant	- Water release operating program
	- Estimated effects of fluctuating flows and quality on wetland	- Periodic drainage of basin for cleaning
	- Storage volume and depth (to inhibit shock loadings to wetland and/or to dechlorinate wastewater)	- Routine maintenance and replacement of aeration equipment
	- Basin side slopes	
	- Basin liner needs	
	- Need for aeration in the basin. If aerators are needed, the aerator size and motor horsepower	
Flow Distribution a) Distribution Piping	- Length and location of piping	- Periodic pipeline inspection, particularly at disposal location
	- Diameter(s)	
	- Number of branches	- Pipeline markers
	- Size of opening at disposal location	- Energy for pumping (if needed)
		- Spray nozzle cleaning & repair
	- Pumping requirements (if needed)	- Replacement costs for piping, and discharge fixtures (spray nozzles, gates, etc.)
	- Use of sprayers (if used)	
	- Method of installation--buried or suspended	
	- Need for insulation of piping (if above ground)	
	- Dewatering needs	

Table 6-3. Continued.

Option Type	Design Parameters	Operation-Maintenance-Replacement Needs
b) Multiple discharge points	- Size and location of flow splitting equipment	- Routine maintenance & replacement of equipment
	- Location of discharge points based on density & diversity of vegetation	- Periodic vegetation control
		- Periodic sediment removal around discharge outlets
c) Multiple cells	- Resting/drydown time needed for wetland type	- Routine operation & maintenance & replacement of flow control equipment
	- Detention time of each cell	- Periodic vegetation control (if needed)
	- Definition of boundary based on flowthrough patterns	
	- Flow control equipment	
Chlorination or any other chemical additions	- Wastewater detention time in chlorine contact chamber (size of chamber based on maximum daily flow)	- Energy for mixing - Energy for chlorinator
	- Chlorine dosage given desired level of disinfection and chlorine residual	- Chlorine (in gaseous or liquid form)
Dechlorination a) Retention	- Retention time of storage facilities for chlorine dissipation	- Maintenance of pond - Monitoring of chlorine residual
	- Level of acceptable chlorine residual	
b) Aeration	- If aeration used, air requirements in cubic feet/sec (m^3/sec)	- Energy requirements
	- If DO steps used; flow capacity, and height of steps	- Maintenance & replacement of equipment

sedimentation. Low velocity sheet flow in a wetland enhances settling and other assimilative processes. It has been suggested that scour velocities could be achieved to flush a wetland periodically of accumulated sediment. The danger of high velocities are excessive erosion, undermining of vegetation and short-circuiting wetland processes. All of these can occur normally under flood conditions but would require careful management if implemented as part of an O&M program.

Settling and scour are largely dependent on particle size. Generally, a velocity greater than 0.50 m/sec (approximately 1.5 ft/sec) is needed to keep small sand particles in suspension. At lower velocities they settle out. For organic solids, velocities below 0.20 m/sec (approximately 0.66 ft/sec) are necessary for settling. Velocities in the range of 0.30 to 0.50 m/sec can resuspend or scour organic solids (Rich 1973). More detailed analyses based on particle size should be conducted if settling is an objective of the system.

Given a constant flow, Q, the velocity (V) is a function of cross-sectional area (A) as shown by the equation:

$$V = \frac{Q\ (\mathrm{ft}^3/\mathrm{sec})}{A\ (\mathrm{ft}^2)}$$

Wastewater applied through a larger area, as can be achieved by the distribution system, will have a lower velocity. To determine velocity, the roughness coefficient and slope need to be determined. A derivation of Manning's equation, as presented in Section 9.5, can be used under some circumstances to assess velocity. The values used for Manning's roughness coefficient are important, and a method for estimating adjustment factors based on watershed characteristics is also discussed in Section 9.5. These calculations are particularly applicable for flow-through type wetlands. Systems that are hydrologically isolated such as cypress domes are not effectively analyzed by these equations. Systems with irregular shaped bottoms may require special considerations in these calculations to exclude wetted areas and to vary the roughness coefficient.

A discharge in South Carolina provides a good example of the potential effects of velocity on a wetland. A channel has cut through the wetland from the point of discharge as a result of a large flow at high velocities, short-circuiting normal wetland processes. Had the wastewater been discharged through a multi-port system the formation of a channel, with resulting open-channel flow, may have been averted.

Residence Time. The determination of residence time depends on knowledge of the area of inundation. Field generated relationships between depth and area of inundation could be established, similar to stage/cross-secional area correlations for free-flowing streams. If a reliable, representative cross-section of a wetland can be obtained, this should be helpful for estimating the area and volume of water at different stages or depths. Residence time depends on flow velocity and length of flow path in free-flowing systems. For systems with regulated flow, the control structure influences residence times. Section 9.5 discusses potential methods for estimating residence time and area of inundation in wetlands receiving wastewater.

Depth. The depth of water in a wetland is dependent on the flows to the wetland, area of inundation, storage capacity (before overflow or discharge occurs), soils and other geomorphologic characteristics (e.g., irregular bottom surface). The depths that will result from a wastewater discharge are important to wetland maintenance and processes. Section 9.5 discusses potential methods for estimating water depths in wetlands receiving wastewater.

Additional Design Parameters. Hydraulic variables affect assimilative processes and control another important design consideration, **constituent loading.** This can be determined by knowing the flow and effluent concentration. To determine total nitrogen loading (NL), for example, the following formula can be used:

$$NL = \frac{\text{(Flow of wastewater) X (Total nitrogen concentration)}}{\text{Effective area of wetland}}$$

This assessment should be conducted for all constituents of importance (e.g., phosphorus, BOD). The analysis should incorporate an evaluation of other major sources to the wetland (i.e., other point and nonpoint sources).

Another aspect of design could be the incorporation of **habitat enhancement** characteristics. Table 6-4 lists design criteria for increasing the waterfowl habitat potential of a wetland. These criteria could be useful for areas that are important habitat (e.g., near flyways, protected species) or that have experienced habitat losses. Habitat enhancement design criteria have been applied successfully to several projects and should be considered for areas of high recreational value. The importance of considering disease vectors (e.g., continued management or disinfection options) is increased for these systems.

Table 6-4. Wetlands Development and Management Guidelines for Waterfowl Enhancement

Parameter	Criteria
Size	o Watershed to wetland ratios of 20:1 (rolling hills) to 30:1 (feather terrain) commonly are recommended by U.S. SCS. Local climatic factors and watershed character may cause significant variation.
	o Several small impoundments have greater positive effect on waterfowl than one large marsh.
Soils	o Most desirable locations are poorly drained soils with high water table or an underlying impermeable layer.
	o Additions of gravel or inorganic soil to existing organic soils can improve stability for wetland vegetation.
Slope	o <1 percent wetland slope recommended.
Configuration	o Irregular shorelines offer substantially greater support for wildlife than small symmetrical impoundments.
Water depth	o Not deeper than about 4 feet for fish and wildlife needs.
	o Lower quality soils (in terms of productivity) should be flooded at shallower depths, with poorest soil flooded <1 foot.
Composition	o Mix of open water and emergent vegetation stands.
	o 50-75 percent of open water shallow enough to achieve emergent plant growth (roughly 2 foot depth).

Source: Adapted from Adams and Dove 1984.

6.4.3 Detailed Cost Estimates

Project or capital costs and operation-maintenance-replacement costs should be revised and finalized by the design engineer once the preferred wastewater management configuration has been selected. The engineer is in a much better position to verify bid prices after developing detailed cost estimates.

For wetland-wastewater systems the major project costs include:

- Preapplication treatment and storage (if used)
- Transmission piping and pumping (if needed)
- Distribution system installation
- Method of access to distribution system (boat, walk-ways, etc.)
- Minor earthwork
- Trench dewatering (if distribution system is buried)
- Above ground installation may require pipe insulation.

Operation, maintenance and replacement costs include the energy, labor and chemicals to operate and maintain the preapplication treatment system, the storage facilities (with or without aeration), transmission facilities (with or without pumping), distribution piping and equipment, as well as possible vegetation control, sediment removal and mosquito control within the wetland. Table 6-5 provides an example format for developing detailed cost estimates for the wetland related facilities of a typical wetland-wastewater system with a storage pond, wastewater transmission by pumping and distribution piping.

Most capital and O&M costs can be estimated based on cost curves available from either EPA publications (such as U.S. EPA 1980) or past contracting bids. When estimating costs, one important element is to be sure the estimates are current. Many available cost curves are based on information from the late 1970's, which are lower dollar estimates than the capital currently needed for the same facilities.

6.4.4 Specifications and Drawings

The primary outputs of a detailed design effort are written specifications that outline a contractor's procedures and drawings of the proposed facilities. The purposes of providing specifications and drawings are traditionally to guide the contractor in establishing construction costs and to assure that the installed facilities are located and situated precisely as desired by the municipality or regulatory agency.

Table 6-5 Detailed Capital Cost Estimate for a Typical Wetland-Wastewater System.

Alterations or Supplemental Facilities at the Treatment Plant

Storage Pond/basin $ ________
Earthwork $ ________
Pond Liner (if needed) $ ________
Aerators (if needed) $ ________
Disinfection Facilities $ ________
Additional site pumping and valves $ ________
Access roads and other site work $ ________
Instrumentation and electrical $ ________

Subtotal $ ________

Transmission to Wetland

Pumping facilities (if needed) $ ________
Piping (forcemain or gravity) $ ________

Subtotal $ ________

Wetland and Distribution System

Distribution piping
Pipe (installed) $ ________
Fixtures (if used) $ ________
Flow splitting facilities (if used) $ ________

Access walkways $ ________
Access roadway to wetland site $ ________
Fencing and signs $ ________
Monitoring wells $ ________
Pipeline markers $ ________

Subtotal $ ________

Architectural and engineering fees $ ________
Legal and administrative $ ________
Contingencies $ ________

Subtotal $ ________

Land for additional facilities at the treatment plant $ ________
Easements for transmission facilities $ ________
Wetland purchase (if needed) $ ________

Subtotal $ ________

TOTAL CAPITAL COSTS $ ________

Specifications also can be utilized to aid construction requirements that enhance the project. Such additional requirements can include requiring construction to take place during certain months of the year and requirements to avoid certain locations that may be very environmentally sensitive. A list of the items that can be specified to control adverse effects of construction is included as Table 6-6. Typically, such items are not included in contract specifications. Regulatory agencies can encourage facility owners to incorporate at least some of the ideas listed in Table 6-6 to help assure a wetland is not disturbed unnecessarily by construction activities.

Drawings can be simple, but they should include alignments, locations and elevations of the proposed facilities. A licensed sanitary engineer can assist with preparing drawings and with any other engineering activities associated with wastewater facilities. Some general specifications recommended for pipelines installed in wetlands are included in Table 6-7.

Table 6-6. Specifications for Wetland-Wastewater Facilities that Help Control Adverse Effects of Construction.

- Permit construction to occur only during periods that a wetland scientist determines are least damaging to the local wetland ecology.
- Use access vehicles and boats that minimize wetland disturbance.
- Employ construction methods to minimize spills of fuels and oils.
- Establish the maximum time a pipeline trench is allowed to be open at any one location (if piping is buried).
- Minimize vegetation disturbance, especially disturbance to trees in forested wetlands.
- Require that all soil disturbed during construction be replaced to original contours and to its original location.
- Protect wetland from sediments resulting from offsite construction by using runoff control technique.
- Minimize the wetland surface area disturbed.
- Place all ancillary construction facilities on upland areas such as field office and equipment storage areas.

Table 6-7. Specifications for Pipelines in Wetlands

- Specify aluminum irrigation pipe or plastic (PVC) pipe.
- For pipelines lying on soil, provisions are needed to prevent sinking when bearing strength of soil is weakest and pipe is full (log or platform support, or elevated).
- Trenches are not recommended due to wetlands alteration, the possibility of required approval from the Army Corps of Engineers and short-circuiting of wetland inflows.
- Install when soil has most bearing strength and vegetation is least damaged.
- Drain during cold weather to prevent ice damage.
- Specify low maintenance equipment (equipment manufacturers vary in the types of pipes, gates, diffusers and sprayers they offer).
- Specify materials that maintain structural stability in wet environments.

Specifications for installing a wastewater system within a wetland that promote effective operation, maintenance and replacement are discussed in Chapter 7 of this Handbook.

6.5 CREATED WETLANDS

While natural freshwater wetlands are the primary focus of this Handbook, wetlands created for the purpose of wastewater treatment merit discussion. Created wetlands are currently being used for wastewater management in New York, Iowa, Ontario, Pennsylvania and California. They are being considered for use in Florida and offer a potential alternative for the other Region IV states as well. The use of created wetlands for wastewater management is addressed here because:

1. Some scientific and engineering information from created systems may be applicable to natural systems.
2. Created wetlands may be a viable alternative to communities that do not have a suitable natural wetland.

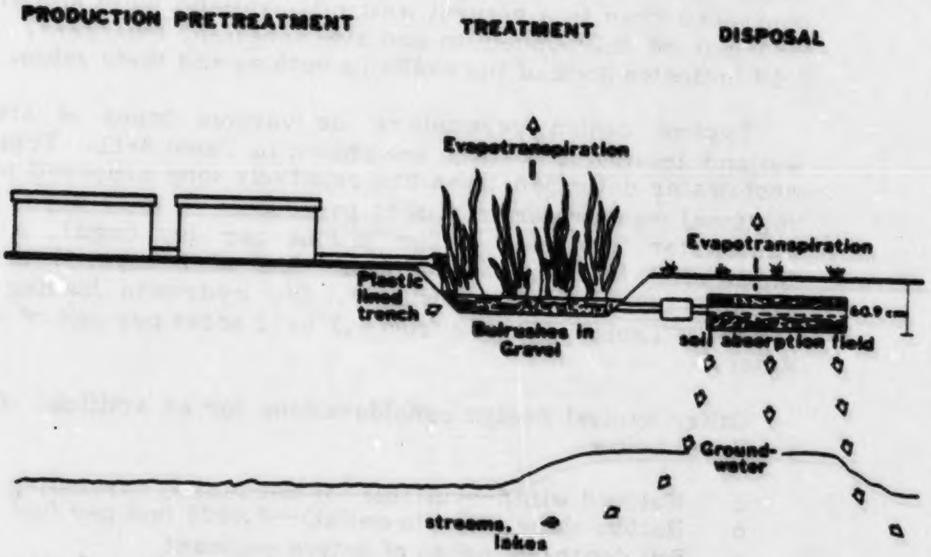
The use of natural and created wetland alternatives typically is land-intensive compared to conventional treatment systems that discharge to receiving waters. In comparison to other alternatives, however, wetlands use can prove cost effective depending on relative land costs, distance to an appropriate site and other site-specific factors. Figure 6-6 shows an example of a created wetland system.

Given a natural wetland of adequate size and reasonable proximity to a wastewater treatment plant, the created wetlands treatment system is generally more capital and energy intensive than a natural wetland of equivalent capacity. This, however, would depend greatly on the design of the created system and largely on its degree of mechanization. The O&M costs of created systems also tend to be higher.

Some cost-recovery may be obtained from both natural and created wetlands used for wastewater management. Increased growth rates have been cited in some natural forested wetlands receiving wastewater, leading to increased timber harvests. The water conservation achieved by recycling wastewater through wetlands has also been noted. Created wetlands often are composed of harvestable biomass which can then be used for food (primarily for cattle or other grazers) or energy production. Unless this biomass is used as such, it is probably more cost-effective not to harvest, unless harvesting is essential to optimize treatment processes.

Typically, created wetlands can be more precisely planned and designed for wastewater management use than natural wetlands. Further, created wetlands are not "waters of the U.S." and, therefore, are not regulated to the same extent as natural wetlands. The objective of created systems clearly can be defined as treatment of wastewater and be designed to optimize treatment processes.

Figure 6-6. Components of a Created Marsh Treatment System


PRODUCTION
PRETREATMENT
TREATMENT
DISPOSAL
Evapotranspiration
Evapotranspiration
Plastic lined trench
Bulrushes in Gravel
60.9 cm
soil absorption field
Ground-water
streams, lakes

Source: Adapted from C.W. Fetter, W.E. Sloey and F.L. Spangler 1976.

defined as treatment of wastewater and be designed to optimize treatment processes.

Table 6-9 summarizes the types of created wetland systems. Marshes and trenches are the two basic types of wetlands used in conjunction with ponds and/or meadows.

Some engineering options which usually are not suitable for use in natural wetlands may be quite suitable for use in created wetlands:

- Periodic flushing of the wetland
- Selection and planting of vegetation
- Harvesting vegetation
- Covering the wetland with a greenhouse-type solar cover
- Installing a liner beneath the wetland
- Recirculating wastewater through the wetland.

Water levels in a created wetland can also be more easily controlled than in a natural wetland. Aquatic plant and animals also can be introduced to achieve enhanced treatment. Table 6-10 indicates some of the available options and their value.

Typical design parameters for various types of artificial wetland treatment systems are shown in Table 6-11. Typically, wastewater detention times are relatively long compared to conventional wastewater treatment processes: 6 to 10 days. For a wastewater flow of 1 million gallons per day (mgd), a water depth of 3 feet and a treatment time of 6 days, 6 acres of wetlands are needed. Similarly, the hydraulic loading rates shown in Table 6-11 vary from 0.2 to 12 acres per mgd of wastewater.

Other typical design considerations for an artificial wetland are listed below.

- Wetland width--suitable for mechanical harvesting
- Bottom slope (inlet to outlet)--0.0025 feet per foot
- Soil depth--6 inches of native sediment
- Clay liner (if any)--6 inches of compacted, native clay
- Pipe material: perforated, 6-inch PVC

Created systems are reported to be more efficient in removing phosphorus, nitrogen and COD from wastewater than are natural wetlands. Table 6-12 indicates general removal efficiencies in natural and created wetlands receiving wastewater. The low phosphorus removal reported for both systems suggests that some type of pre-treatment for phosphorus may be necessary where phosphorus removal is important, particularly for natural systems.

Table 6-9. Artificial Wetlands Use for the Treatment of Wastewater or Stormwater.

Type	Description
Marsh	Areas with impervious to semi-pervious bottoms planted with various wetlands plants such as reeds or rushes.
Marsh-pond	Marsh wetlands followed by pond (and perhaps a meadow).
Pond	Ponds with semi-pervious bottoms with embankments to contain or channel the applied water. Often, emergent wetland plants will be planted in clumps or mounds to form small subecosystems.
Seepage wetlands	Wastewater irrigated fields overgrown with volunteer emergent wetland vegetation as a result of intermittent ponding and seepage of wastewater.
Trench	Trenches or ditches planted with reeds or rushes. In some cases, the trenches have been filled with peat.
Trench (lined)	Trenches lined with an impervious membrane usually filled with gravel or sand and planted with reeds.

Source: Chan et al. 1982 (derived in part from U.S. EPA 1979).

Table 6-10. Role of Aquatic Organisms in Renovating Wastewater.

Organism	Remarks
Floating aquatic plants Water hyacinth (*Eichhornia* spp.)	Its extensive root system has excellent filtration and bacterial support potentials, but extends less than 8 in. (200 mm) below the water surface in most wastewater treatment applications. Hyacinths will not winter-over in cooler climates.
Water primrose (*Ludwigia* spp.)	The filtration and bacterial support potentials of the primrose's submerged stems and roots are less than those for the hyacinth. Primrose roots may extend to over 2 ft (600 mm) below the water surface. This plant survives in colder climates but is winter dormant even in mild climates.
Emergent aquatic plants Cattails (*Typha* spp.) Bulrush (*Scirpus* spp.)	The submerged portion of the stems of these plants has less filtration and bacterial support potential than the roots of floating plants, but has the advantage of extending through the entire water column. These plants survive in colder climates. Though they tend to be winter dormant, their physical structure remains intact during dormancy.
Submerged aquatic plants Algae	Algae release oxygen to water at the expense of creating SS and BOD. Algae respire at night. Algae can be grown to raise the pH to volatilize ammonia and then be removed. Successions in algal population, particularly in fall, cause odors.
Pondweeds (*Potamogeton* spp.)	The filtration and bacterial support potentials of this category of plant are unknown. Other effects of submerged macrophytes are similar to those described for algae, except that SS problems are not created.
Aquatic animals Zooplankton	These organisms feed on algae and other suspended particulates. Their presence and effect are difficult to manage.
Fish Blackfish Carp Catfish Mosquito fish	Fish serve in a role similar to that described for zooplankton. Fish can also be used to reduce the vegetative standing crop and - control mosquitoes. Fish populations are manageable.

Source: Stowell et al. 1981.

Table 6-11. Preliminary Design Parameters for Planning Artificial Wetlands Wastewater Treatment Systems[a]

Type of System	Detention Time, days Range	Detention Time, days Typical	Depth of Flow, m (ft) Range	Depth of Flow, m (ft) Typical	Hydraulic Loading Rate ha/1000 m^3/day (acre/mgd) Range	Hydraulic Loading Rate ha/1000 m^3/day (acre/mgd) Typical
Trench (with reeds or rushes)	6-15	10	0.3-0.5 (1.0-1.5)	0.4 (1.3)	1.2-3.1 (11-29)	2.5 (23)
Marsh (reeds rushes, others)	8-20	10	0.15-0.6 (0.5-2.0)	0.25 (0.75)	1.2-12 (11-112)	4.1 (38)
Marsh-pond						
1. Marsh	4-12	6	0.15-0.6 (0.5-2.0)	0.25 (0.75)	0.65-8.2 (6.1-76.7)	2.5 (23)
2. Pond	6-12	8	0.5-1.0 (1.5-3.0)	0.6 (2.0)	1.2-2.7 (11-25)	1.4 (13)
Lined trench	4-20	6			0.16-0.49 (1.5-4.6)	0.20 (1.9)

[a] Based on the application of primary or secondary effluent.
Source: U.S. EPA 1979.

m - meters; m^3 - cubic meters
ha - hectares
mgd - millions of gallons per day

Table 6-12. Reported Removal Efficiency Ranges for the Constituents in Wastewater in Natural and Artificial Wetlands.

Constituent	Removal efficiency, % Natural wetlands Primary	Natural wetlands Secondary	Artificial wetlands Primary	Artificial wetlands Secondary
Total solids		40-75		
Dissolved solids		5-20		
Suspended solids		60-90		
BOD_5		70-96	50-90	
TOC		50-90		
COD		50-80	50-90	
Nitrogen (total as N)		40-90	30-98	
Phosphorus (total as P)		10-50	20-90	
Refractory organics				
Heavy metals[a]		20-100		
Pathogens				

[a] Removal efficiency varies with each metal.
Source: Tchobanoglous and Culp. 1980.

Operation of created wetlands usually incorporates treatment as the main objective with size requirements potentially being less than natural systems and regulatory constraints lessened, the operator of a created system has more latitude than the operator of a natural system. However, because created wetlands are used primarily for treatment rather than for polishing or disposal, as is common for a natural system, continued monitoring of the created system must be undertaken. As with any treatment system that relies on biological processes, the organisms achieving the treatment must be kept viable. Although the use of created wetlands for wastewater management is receiving increased attention and being practiced at an increasing rate, it remains a new technology requiring higher levels of monitoring and management.

Natural and created wetlands have demonstrated their value in many instances as effective alternatives for upgrading the quality of domestic effluents. The overall advantage of one system over the other depends on many site-specific variables and general treatment objectives. Where wetlands protection issues discourage the use of natural wetlands, where wetlands have been totally destroyed or where no suitable natural site exists, the use of created wetlands is encouraged. Additionally, the use of created wetlands in conjunction with natural wetlands may offer advantages or opportunities not otherwise available and can increase wetlands areas.

6.6 USER'S GUIDE

Chapter 6 provides the information needed to proceed from the planning stages through engineering design utilizing information developed from Chapters 4 and 5. Chapter 4 outlines the planning and assessment involved with screening potential wetland sites for wastewater management use. Chapter 5 presents standards and loading criteria that apply to a wetlands-wastewater system. Ultimately, effluent limitations will determine the loading rates of most important wastewater components. The information contained in Chapter 5 should assist with determining loading rates of components not addressed by effluent limitations.

Figure 6-7 illustrates how engineering planning and design relate to other institutional and scientific elements. The information requisite to these decision points must be gathered and interpreted accurately to make well-informed decisions. These tasks are related to community conditions, existing or proposed treatment plant needs and wetland characteristics. Important wetland-wastewater engineering elements include:

- Wastewater management objective(s)
- Wastewater characteristics
- Pretreatment requirements
- Environmental restrictions, including wetland uses, sensitivity, uniqueness
- Vegetation
- Overall cost effectiveness
- Special measures to enhance system performance
- Contract specifications
- Contract drawings

Another important engineering decision is whether the system will be designed to optimize wastewater renovation or simply to dispose of wastewater. The institutional aspects of this question are addressed in Section 3.3; the technical aspects are discussed in Section 6.2. Wetlands maintenance and protection are management objectives that should be incorporated into all engineering planning and design decisions.

The main user of Chapter 6 is the applicant or applicant's representative (engineer) who must develop a wetland-wastewater system. Regulatory agency personnel should find this chapter helpful in establishing engineering guidelines that optimize both wastewater management objectives and wetlands protection.

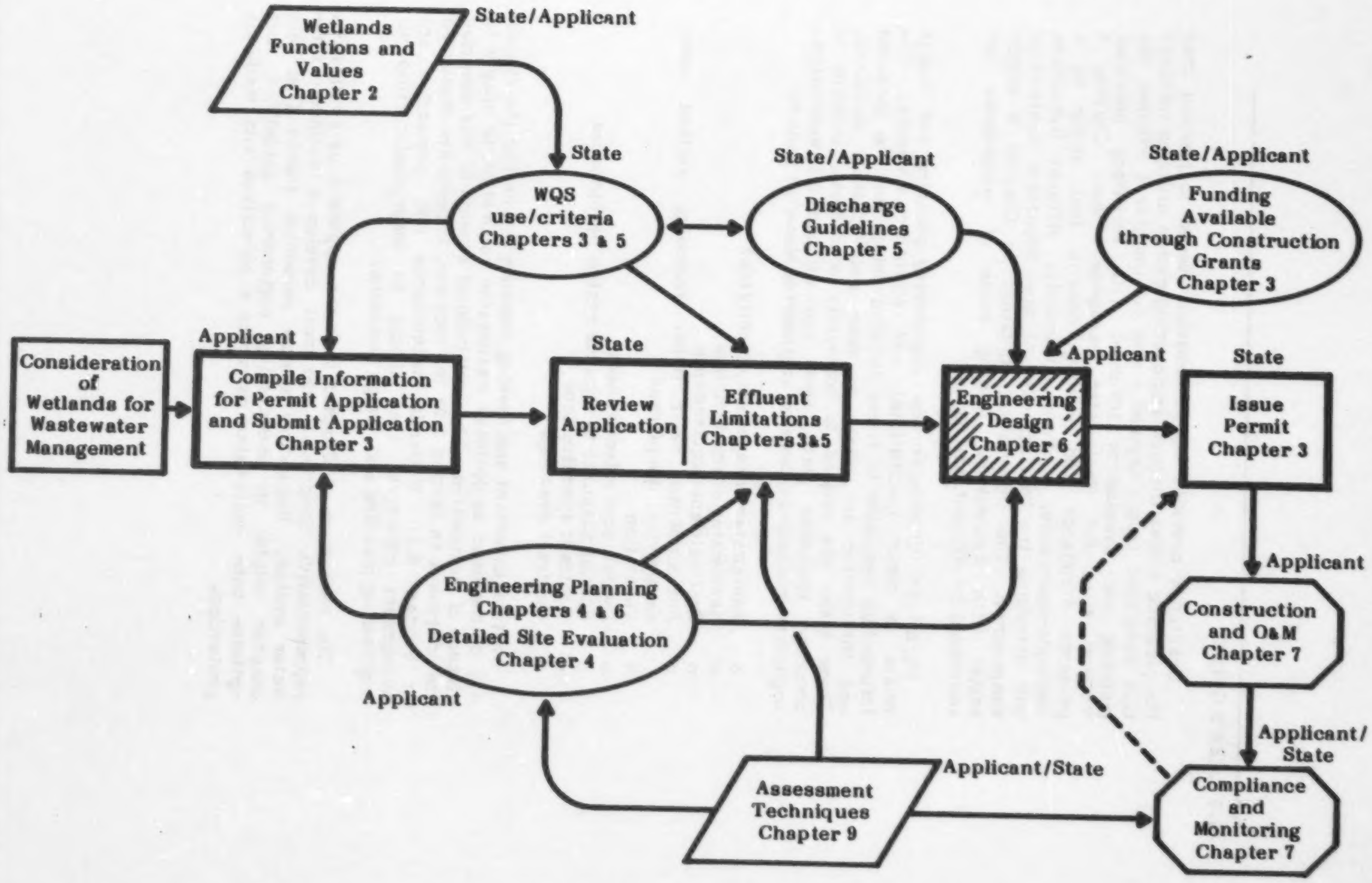

Wetlands Functions and Values Chapter 2
State/Applicant
State
WQS use/criteria Chapters 3 & 5
State/Applicant
Discharge Guidelines Chapter 5
State/Applicant
Funding Available through Construction Grants Chapter 3
Consideration of Wetlands for Wastewater Management
Applicant
Compile Information for Permit Application and Submit Application Chapter 3
State
Review Application
Effluent Limitations Chapters3&5
Applicant
Engineering Design Chapter 6
State
Issue Permit Chapter 3
Applicant
Construction and O&M Chapter 7
Applicant/ State
Compliance and Monitoring Chapter 7
Engineering Planning Chapters 4 & 6 Detailed Site Evaluation Chapter 4
Applicant
Assessment Techniques Chapter 9
Applicant/State

Figure 6-7. Relationship of the Handbook to the Decision Making Process.

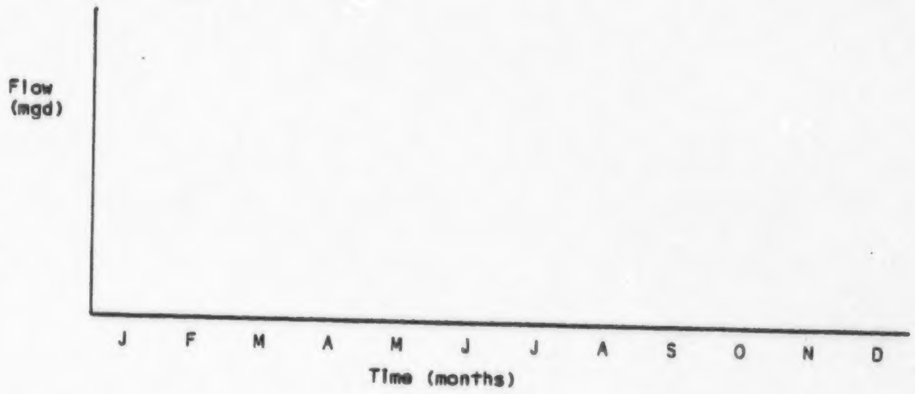
Form 6-A leads a potential wetlands discharger through a series of questions and data collection tasks that provide guidance for planning and designing a wetlands wastewater system. The user is reminded that the engineering planning and design process is concurrent with the permit application process. Contact and frequent communication between the applicant and regulatory agency personnel is necessary to assure that the information required for decision making is efficiently obtained.

FORM 6-A. **Wetlands-Wastewater Management System, Engineering Planning and Design**

ENGINEERING PLANNING

A. WASTEWATER FLOW.

1. Discharge is continuous _____, periodic _____, or seasonal _____.
2. Describe flow volume: Average daily flow _____ mgd
   Average monthly flow _____ mgd
   Average annual flow _____ mgd
3. Chart wastewater flow variations over time (if applicable):



4. Describe effluent (flow leaving the treatment plant) quality:

	Concentration (mg/l)	Loadings (lbs/day)
Organics (BOD_5, COD)		
Suspended Solids		
Dissolved Oxygen		
pH		
Nitrogen		
Phosphorus		
Metals		
Others (explain)		

5. Total volume of storage at treatment plant _____ gallons.
6. What water quality standards need to be met in the wetland and downstream from the wetland?

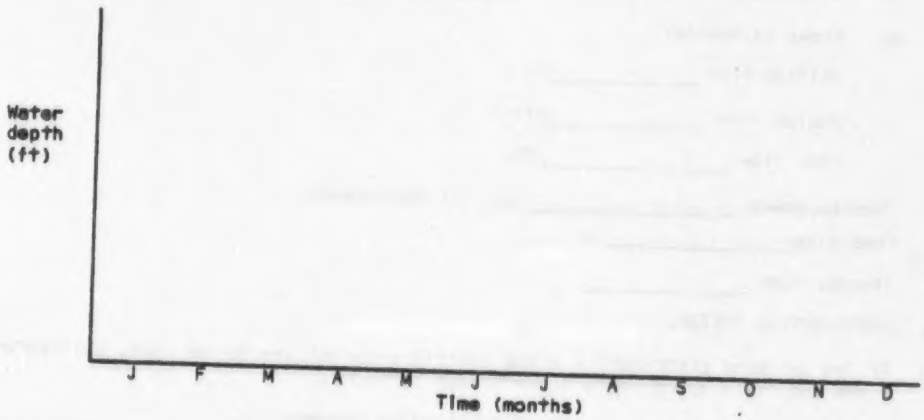
FORM 6-A Continued

B. WETLAND CHARACTERISTICS.

1. Type of wetland ____________________
2. Size of wetland ____________________
3. Is this wetland unique, endangered or of special concern? (See Section 2.3) ____________

   If yes, and it has received preliminary approval for use as a wastewater management system in discussions with concerned agencies, describe methods to be used to mitigate impacts on plant and animal communities.

4. Typical natural hydroperiod, in terms of water depth:
   - a. Minimum __________ feet
   - b. Maximum __________ feet (allow for peak wet weather flows)
   - c. Chart variation in hydroperiod with time.



5. Most prominent wetland vegetation types ____________________.
6. Typical flow-through pattern observed in wetland:

   Channelized ____________________

   Sheet flow ____________________

   Other (explain) ____________________

7. Estimate and delineate effective area of wetland. This determination depends on anticipated flow patterns and distribution method used, as well as the wetland vegetation and soils. (See Form 4-B.)
8. Estimated hydraulic residence time within the wetland ______________ days.

   Section 9.5 discusses derivations and application of the Manning's equation, where depth and residence times can be estimated. Section 9.5 also includes a discussion of adjustment factors for Manning's n, dependent on site-specific watershed characteristics.

FORM 6-A Continued

ENGINEERING DESIGN

A. TRANSMISSION TO WETLAND.

1. Length of transmission piping or channel from treatment plant to wetland _____ feet.

2. Piping:

a) Minimum flow velocity

Initial flow ______________fps

Design flow ______________fps

Peak flow ______________fps

b) Pipe diameter ____________________ inches

c) Pipe material ____________________________

3. Channel:

a) Cross-sectional channel area _______________sq ft

b) Flows in channel:

Initial flow ___________cfs

Design flow _____________cfs

Peak flow _______________cfs

4. Pumping needs _________________ gpm (if applicable)

Pump size ______________ hp

Standby pump ______________

B. DISTRIBUTION SYSTEM.

1. If two or more distribution areas (multiple cells) are to be used, delineate areas on a map and their approximate flow-through patterns.

2. Determine discharge frequency and application pattern ________________________.

3. Location of outfall(s) in wetland:

a) Distance from edge of wetland _________________ ft
b) Locate on map

4. Distribution type:

Single pipe __________________

Multiple pipes _________________

Overland flow _________________

Spray system _________________

Multiple ports or gates _________________

FORM 6-A Continued

5. Method of installation:

Above ground ______________; insulation needed ______ yes ______ no

Below ground ______________; discuss impacts and methods to mitigate impacts.

6. Method of access to distribution system:

Boardwalks ____________________

Roadways ____________________

Boat ____________________

Other (explain) ____

7. Method of marking pipe location:

8. Have resting periods been designed into system? Yes ___ No ___

If not, why not? ____

____

____

C. ALTERATIONS TO TREATMENT PLANT.

1. Need for additional storage ____________________ gals

2. Storage ponds to be aerated _______ yes ___________ no

If yes, air volume needs ___________ cfm

3. Disinfection used:

Chlorination ________________________

Ozonation ____________________________

Ultraviolet light ____________________

Other (explain) ______________________

None * ________________________________

*If no disinfection used, explain how pathogen transmission will be limited and controlled.

4. Dechlorination method (if applicable):

Detention in storage ____________________

Oxygen steps ____________________________

Other (explain) _________________________

FORM 6-A Continued

D. WETLAND MODIFICATIONS.

1. If levees, dikes, or berms are constructed to control water flow in the wetland, describe:

Height ____________ ft

Side slopes ______________

Method for maintaining flow-through patterns ____________________

Slope erosion control ____

2. Artificial substrate (if used):

a) Type and material _______________________

b) Delineate area of wetland to receive substrate ___________________

3. If vegetation is to be planted, describe:

a) Plant types and level of water tolerance ___________________

b) Location of plantings on map

c) Estimated area to be planted _________________ sq ft

4. Discuss the expected impacts from these in-wetland modifications and how they will be minimized to a point where they are more beneficial than harmful.

E. BACK-UP SYSTEM.

1. Is the wetland to be used during winter and wet weather conditions, as well as summer months? Yes ______ No ______

2. What changes, if any, are anticipated in treatment plant performance during these periods?

3. What changes, if any, are anticipated in wetland performance, impacts or processes?

FORM 6-A Continued

4. If wetland is not usable at certain times, describe the back-up disposal system proposed:

Storage ______________________

Other (explain) ______________________

F. OTHER ITEMS.

1. Methods for limiting public access:

Fencing ______________

Signs ______________

Other (explain) ______________________________

2. Methods for protecting wetland area from upstream pollutant inflows, causing additional stress on the wetland:

Sediment traps ______________

Flow storage during times of external stress ______________

Other (explain) ______________________________

3. Methods for maintaining or improving habitat potential of wetland:

Use of design criteria for habitat enhancement? Yes ____ No ____

Proposed planting of vegetation with specific habitat functions? Yes ____ No ____

Designing system so as to reduce vegetation impacts? Yes ____ No ____

4. If optimal renovation of wastewater is anticipated, what assimilation mechanisms have been evaluated?

Soils uptake potential? Yes ____ No ____
Hydraulic variables?
  Retention time Yes ____ No ____
  Velocity Yes ____ No ____
  Depth Yes ____ No ____
  Loading rates based on assimilative capabilities: Yes ____ No ____
  Understanding of water chemistry in wetlands? Yes ____ No ____
  Kinetics affecting water chemistry? Yes ____ No ____

5. If a pilot study is anticipated have:
Objectives been defined? Yes ____ No ____
(e.g., nutrient removal, acceptable hydraulic loading rates)
Specifications have developed? Yes ____ No ____
A monitoring program been designed to account for variables affecting water quality and/or assimilation? Yes ____ No ____
The studies been coordinated with regulatory agency? Yes ____ No ____
Quality control specifications been met? Yes ____ No ____

7.0 PROJECT IMPLEMENTATION

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7.0 PROJECT IMPLEMENTATION

Who should read this chapter? Primarily, potential applicants and their engineers. Also, regulatory personnel charged with monitoring construction activities and wetlands protection.

What are some of the issues addressed by this chapter?

- How can a wastewater system be installed without damaging the wetland?
- What are cost-effective operation-maintenance-replacement options that can enhance system performance?
- Which monitoring procedures can be utilized cost-effectively to assess system performance?

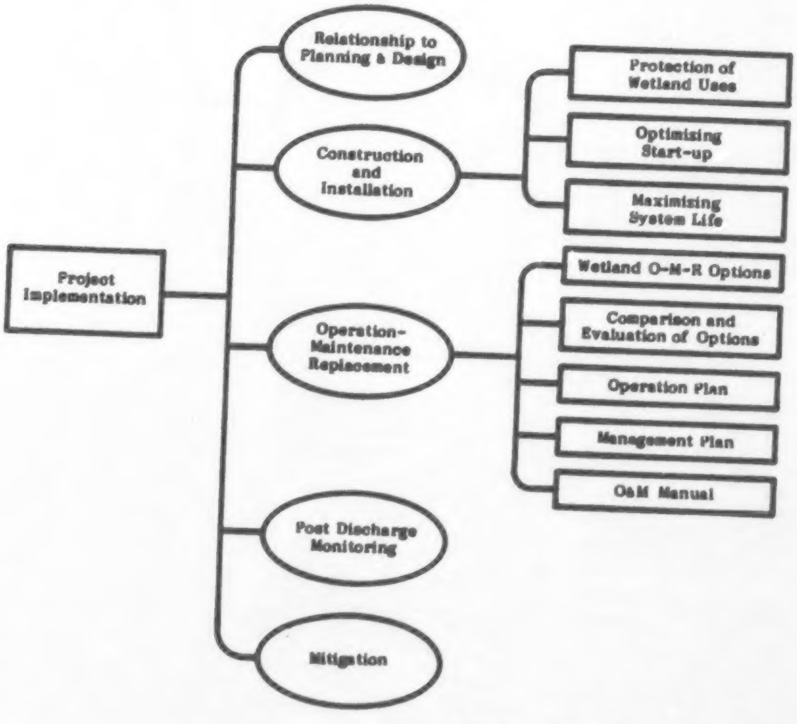

Project Implementation
Relationship to Planning & Design
Construction and Installation
Protection of Wetland Uses
Optimizing Start-up
Maximizing System Life
Operation-Maintenance Replacement
Wetland O-M-R Options
Comparison and Evaluation of Options
Operation Plan
Management Plan
O&M Manual
Post Discharge Monitoring
Mitigation

Fig. 7-1. Overview of Project Implementation.

7.1 RELATIONSHIP TO PLANNING AND DESIGN

The user of this chapter is presumed to have already reviewed Chapter 6.0, Engineering Planning and Design. Proper planning and designing are the first two of the four essential engineering steps: the last two steps, installation and operation-maintenance-replacement, are covered in this chapter. Post-discharge monitoring also is addressed.

The benefits of an effective wastewater management plan and design can be entirely negated by improper installation or inadequate operation and maintenance. Therefore, project implementation should be closely associated to planning and design. In many instances project implementation is based on planning and design (e.g., multiple cell use and schedule). Figure 7-1 outlines the major elements of project implementation.

7.2 CONSTRUCTION AND INSTALLATION

7.2.1 Purpose and Considerations

The objective of construction and installation is to set a system into place at minimum costs, including environmental effects as well as monetary costs. There are several construction-installation procedures which can minimize environmental damages without unnecessary expenditures.

A well-conceived design with clear drawings and well-written specifications is of great help to system installers and will minimize construction costs. Section 6.4.5 specifies important items for effectively controlling wastewater system installation or construction within a wetland.

Installation and construction techniques must respond to the characteristics of the wetland site including:

- Type of wetland (e.g., peat bog versus reed meadow)
- Soil depth to stable material
- Erodability of wetland material
- Water velocities and circulation patterns
- Ecological sensitivity of the wetland system.

In the pre-construction meeting, specific installation techniques should be developed, discussed and agreed upon by the discharger, regulatory personnel and construction contractor. Specific wetland concerns to be addressed include: **protection of wetland uses, optimizing start-up and maximizing system life.**

7.2.2 Protection of Wetland Uses

The range of wetlands functions and values, or uses, are presented in Chapter 2. Since these vary for different wetlands, the specific attributes of each wetland should be identified. Two areas of action can be taken to protect wetland uses during construction. The first is to employ techniques that minimize short and long term impacts from construction. The second is to assure that the system is installed or constructed as it was planned and designed.

The degree of impact on a wetland site during construction is related to the spatial relationship (how close the wetland is to the construction), the length of time construction continues and the seasonal timing of construction. Darnell (1976) has explored these factors. Clearly, if construction occurs directly in the wetland, major disturbance can result. However, the disturbance can be minimized if the timing of construction is selected during low productivity periods (e.g., winter months when most vegetation is dormant) and not during sensitive breeding periods. Although short term impacts on the wetland may be significant, long term impacts are minimized, and the wetland recovery period is shortened.

In addition to proper timing, there are some **construction techniques** that may be helpful in minimizing both short term and long term impacts including:

- Minimizing all construction slopes to reduce erosion potential
- Avoiding soil compaction where not required
- Revegetating disturbed wetland areas with water-tolerant species
- Constructing levees at least ten feet wide and one foot above the highest water level for ease of access (ASCE 1978)
- Maintaining strict control of water entering and leaving the site during installation to avoid unnecessary soil erosion and inhibition of installation activities
- Installing sediment traps in areas that receive runoff from upstream
- Offsite construction of wastewater facilities
- Avoiding the installation of pipelines or facilities directly adjacent to a wetland during ecologically-sensitive period (e.g., during reproductive periods for sensitive wetland species).

Long term impacts generally result from damage to systems that have long life cycles, such as wildlife, trees and human use functions (flood storage and others). Also, long term impacts result from a permanent and major system change, such as a significant change in water levels. Construction and installation techniques should be established to minimize impacts on long life-cycle systems and to prevent major permanent change.

Quality control of **installation procedures** is necessary to assure that what was intended is actually constructed and that the wetlands are protected. Some general quality control guidelines include:

- Assure that specifications include materials, equipment and timing of installation
- Select a contractor or pipeline installer that is experienced with wetland installations or wet soil conditions
- Include a wetland scientist in the pre-construction conference to discuss and plan specific actions to minimize impacts
- Provide an installation inspector (perhaps a wetland scientist) experienced in evaluating wetlands systems, construction activities and impacts

- Regulatory agencies may choose to have a wetland scientist periodically inspect progress as the site work continues
- Test the installed system before the installer leaves the site to minimize system breakdowns
- Require the installer to regrade the disturbed area as closely to pre-installation conditions as possible.

7.2.3 Optimizing Start-up

The major concern during start-up is minimizing the impact of overloading the wetland capacity from accidental discharges, imbalanced flow distribution or other system failures. The following considerations are recommended for general start-up conditions. However, the needs of the specific wetland site should be addressed in developing a start-up procedure.

The determination of **start-up time** for a wetlands discharge includes the following four components.

1. The time lag between the end of construction and start-up should be minimized to avoid prolonged periods in which in-place facilities are unused.
2. Avoid startup during sensitive wildlife breeding periods or during periods of wetland stress from other disturbances.
3. Coordinate start-up with the natural hydroperiod of the wetland. Apply when dilution capacity exists, but not when a hydraulic overload might occur. Also, avoid start-up during natural dry-down periods.
4. Start-up during low productivity seasons would tend to lessen the impact of a system failure on wetland vegetation. However, start-up during the highest productive time will act to improve wetland treatment ability and protect downstream waters.

After the appropriate timing is established for initiating the discharge, the following procedures should be followed.

- A gradual buildup of wastewater flow volumes should take place over a several week to six month period, to allow the wetland time to adjust. Close monitoring during this start-up period is strongly encouraged to observe proper system functioning and impacts on the wetland (see Section 7-4).
- Variation in flow distribution patterns (if facility is designed for flexible flow patterns) should be carried out to determine the pattern that optimizes uniform distribution or meets the goals of the design.
- Equipment testing should be carried out as is done with other wastewater treatment systems.

7.2.4 Maximizing System Life

During construction/installation, certain procedures can simplify future operation-maintenance-replacement and extend system life. These include:

- Installation of visible pipeline markers for easy location of both above ground and buried piping.
- Utilizing flexible pipe that will reduce maintenance and replacement needs.
- Utilizing water tolerant materials for pipe support structures, access walkways and distribution systems.
- Avoiding the erection of barriers either from earth moving or from installing facilities that may interfere with wetland flow patterns.
- Removing all leftover construction materials from the site.

As discussed with design considerations, maximizing system life relates primarily to monitoring natural functions and values. System life is threatened if natural processes are significantly altered. Major changes in the system, e.g., a vegetation species shift, can in some cases alter the system from that originally incorporated in design. This can lead to modifications in assimilative capacity as well. The primary mechanism for maximizing system life may be in the design of the system (e.g., maintaining conservative loadings, sheet flow). Operation practices are equally important, however, by maintaining wetland hydroperiod through flow regulation, providing "resting periods" for wetlands, assuring sheet flow is obtained and recognizing the natural ecological functions of the wetland throughout the operation of the system.

7.3 OPERATION-MAINTENANCE-REPLACEMENT

7.3.1 Purpose and Considerations

The operation-maintenance-replacement (OMR) program for the wetland-wastewater facility should be geared to meet the treatment and disposal system's level of need. Equipment and facilities used in a wetland system should not be complex, but longlasting with proper and routine maintenance.

The types and amounts of OMR to be conducted can vary widely depending upon decisions made while the system is being designed. For example, if wastewater storage facilities and/or alternative wastewater disposal techniques have been designed and installed, operation can be more flexible than if these options for controlling wastewater flows are not available. Water flow paths can be altered if multiple discharge points to a wetland are available. Vegetation may also be controlled via harvesting or the use of some other type of vegetation control. Other types of OMR activities include periodic inspections and preventive maintenance of facilities.

The development of an OMR program includes the preparation of an operation plan, a management plan and an operation and maintenance manual. These tasks are discussed in more detail later in this section. Some general **recommendations for promoting proper OMR** are as follows.

- Limit changes in water levels and flow patterns resulting from wastewater flow fluctuations by controlling application rates. This recommendation is based on the knowledge that hydrologic levels are important to wetland functions.
- Combine operating requirements of the wetland wastewater system with treatment plant operations. A combined OMR manual for the treatment plant and the wetland could be developed. In addition, the same personnel could operate the treatment plant and monitor the wetland.
- Follow maintenance intervals for equipment recommended by manufacturers (e.g., for sprayers).
- Conduct periodic inspections in conjunction with a monitoring program.
- Let the natural wetland manage itself as long as no visible stress occurs. Generally, naturally occurring processes result in less adverse effects than if man-induced processes are introduced.

7.3.2 Wetland OMR Options

Specific OMR activities vary widely depending upon the objectives being sought. From an engineering perspective, several different OMR objectives could be considered. Table 7-1 lists several of the objectives that could influence OMR decisions.

Table 7-1. Potential OMR Objectives as Basis for OMR Decisions

1. Maximize wastewater assimilation.
2. Minimize OMR costs.
3. Maintain engineered facilities.
4. Minimize adverse effects on downstream water quality.
5. Minimize odor production and public health concerns.
6. Minimize stress on the wetland.

Ultimately, OMR objectives should match those of engineering design, which are based on water quality standards and effluent limits. Hence, decisions made during planning and design affect (and largely dictate) the OMR activities to be conducted. A detailed list of actions that respond to each objective is included in the User's Guide (Section 7.6). Selection of the most beneficial operation methods must be based on knowledge of the particular wetland receiving wastewater. Dischargers are encouraged to work continuously with state permitting agencies and the state fish and wildlife agencies.

Operation and maintenance options, at a minimum, should meet objectives similar to those discussed for construction:

- Protect of wetland uses and public health
- Optimize assimilation
- Maximize system life.

Several O&M alternatives have been employed for existing discharges, and results suggest they might be useful in meeting these objectives. O&M alternatives include:

1. **Storage to avoid shock loadings.**

   To maintain the desired flow characteristics of properly treated wastewater, storage may be necessary at times due to treatment plant upsets, I/I problems or other system failure. The use of storage, power failure alarms and a standby power source help avert potential problems. Automatic monitoring of dissolved oxygen, turbidity and pH also might be desired. Evaluate the effectiveness, feasibility and cost of providing 12 to 24 hours or more of wastewater storage volume.

2. **Adjusting residence time by hydraulic loading.**

   Assimilative capacity is largely dependent on the retention time in the wetland. Given wetland size and vegetation type on which initial determination of residence times are based, the primary management tool is adjusting hydraulic flows. If stormwater or other water sources change the residence time upon which system design is based, wastewater flows could be altered to maintain the prescribed flow. Diversions of upstream or stormwater flows under some conditions might also be considered to maintain designed residence times. Berms or wiers are also used for this purpose in some situations. The key is maintaining natural flow levels and flow through times to the extent possible.

3. **Intermittent discharges.**

   Another method of maintaining the natural hydroperiod to the extent possible is intermittent flows. Some communities may only need a summer or winter discharge depending on population fluxes. Such intermittent discharges should be matched with the natural hydroperiod. If a year-round discharge is needed, intermittent discharges or resting periods may be necessary to maintain the wetland. Three primary options are available: multiple cells within the wetland, rotating flows from one cell to another allowing for resting periods; use of more than one wetland; and storage. The determination of which option is best depends on wetland availability, flow volumes and the need for a resting period (depending on the proposed hydraulic loading and wetland type).

4. **Discharging to areas of dense vegetation.**

   While not essential to wetlands maintenance, the use of discharging to vegetated "clumps" within a wetland (as shown in Figure 7-2) may improve assimilation. The vegetation acts to slow down the water, enhancing settling and other assimilative mechanisms. The vegetation also traps particulate matter and solids. Such a practice may require managing the area of discharge; but it could result in improved assimilation, particularly where retention times may not be as long as desired.

5. **Nitrogen removal by controlling water depth.**

   One major pathway for nitrogen removal in a wetland is denitrification, which occurs only in anaerobic (oxygen lacking) environments. Denitrification occurs primarily in the soil rather than the water column, and it has been shown an aerobic water column can prevent the loss of nitrogen gas produced from denitrification. One management approach suggested is controlling water depth, thereby limiting the amount of aerobic water above anaerobic sediments and enhancing the loss of nitrogen via denitrification. This can be achieved with wetlands-wastewater systems that have flexible hydraulic loading regimes. Other management options exist for controlling the form of nitrogen such as aeration or pH adjustment (Gearheart 1983).

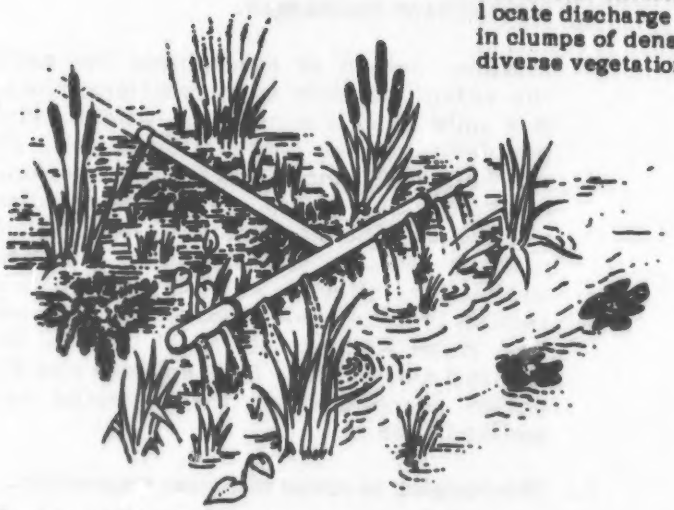


Figure 7-2.
For better filtering action, locate discharge outlets in clumps of dense and diverse vegetation

Source: CTA Environmental, Inc. 1985.

6. Vegetation Planting.

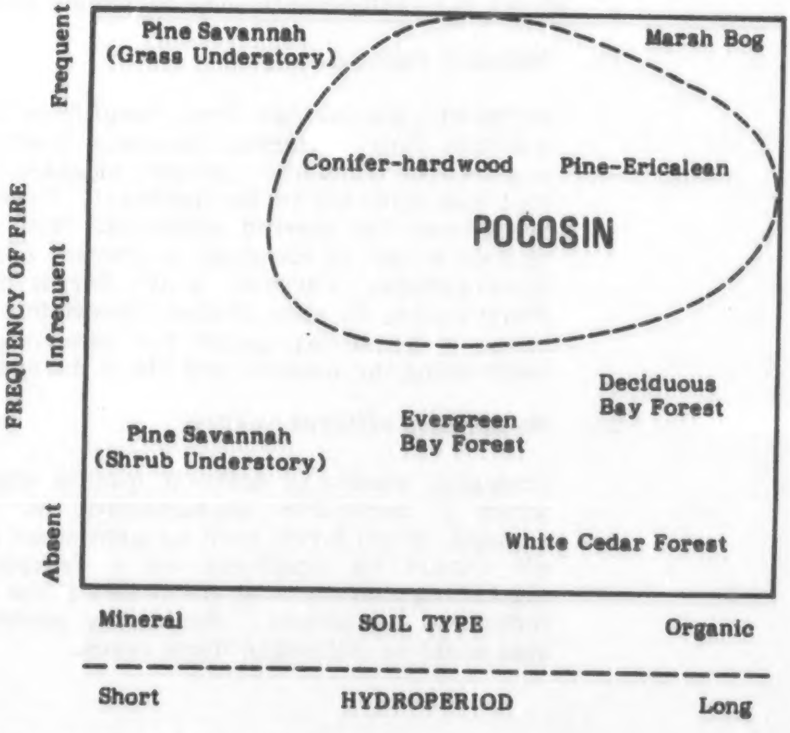
Planting vegetation that may be more water tolerant, provide greater filtration or increase vegetative diversity is an option for various wetland conditions. Wetlands that have been previously degraded can be improved over time through planting. Increased density of vegetation near outlet points in the wetland can improve the wetland's assimilative capacity. Often, however, allowing natural vegetation to develop will decrease the likelihood of nuisance vegetation becoming dominant.

7. Harvesting/Burning.

Depending on wetland conditions and wastewater quality, the type and growth rate of vegetation will vary. Often a vegetative monoculture will develop due to natural competition of wetland vegetation. Harvesting these plants periodically will allow for greater diversity. A second use of vegetation harvesting is to remove nutrients or toxins from the system while they are bound up in the physical vegetation structure and before they are released to the system. Also, periodic harvesting of rooted and floating plants can enhance wastewater assimilation.

Burning is used to control monocultures and to provide the "burn" environment needed periodically by some wetlands as part of their natural regeneration processes. The frequency of burning depends on the type of wetland. Figure 7-3 shows the natural relationships between vegetation, hydroperiod and frequency of fire.

Figure 7-3. Relationship Between Hydroperiod, Vegetation and Frequency of Fire.


FREQUENCY OF FIRE
Frequent
Infrequent
Absent
Pine Savannah (Grass Understory)
Marsh Bog
Conifer-hardwood
Pine-Ericalean
POCOSIN
Deciduous Bay Forest
Evergreen Bay Forest
Pine Savannah (Shrub Understory)
White Cedar Forest
Mineral
SOIL TYPE
Organic
Short
HYDROPERIOD
Long

Source: Sharitz and Gibbons 1982.

8. **Maintenance of open water.**

The maintenance of open water within a wetland has been shown to be important to some water quality characteristics. The amount of open water is controlled by the presence of emergent vegetation, floating vegetation and land masses within a wetland. As noted in Gearheart et al. (1983), open water is beneficial to phytoplankton communities, an important oxygen source during daylight hours. Open water is also valuable to the control of mosquitoes and die-off of bacteria. Too much open water can lead to phytoplankton blooms and increased suspended solids. Twenty to forty percent open water with vegetative barriers are suggested. Other studies suggest up to 50 percent open water for wildlife enhancement. Management strategy objectives should help define the optimal percent of open water for a given wetland.

9. **Introduction of mosquitoe fish.**

If mosquitoe populations become a problem as a result of a wastewater discharge, the introduction of mosquitoe fish may be beneficial for control. The technique has been used primarily in created wetland systems or lagoons but has been shown to be effective in some controlled wetland areas.

10. **Sediment removal.**

Sediment removal has been helpful in some situations to maintain flow patterns, decrease benthic oxygen demand and remove nutrients, metals, biocides and other material that has collected in the sediment. Primarily, applications have been for created wetlands. With natural wetlands, caution would be required to prevent compaction and other disturbances. Further, a 404 Permit may be necessary. Nonetheless, in some limited circumstances this may prove to be a beneficial option for enhancing assimilation and maintaining the wetland and life of the system.

11. **Maintaining effluent quality.**

Frequent testing of effluent quality should be conducted when a particular characteristic is of concern. For example, if pH levels must be maintained in a certain range, pH should be monitored on a regular basis. Effluent monitoring also might be conducted if the wastewater has an industrial component. Monitoring pretreatment processes also could be utilized in these cases.

12. **Facility Inspections.**

    Since wetlands-wastewater systems still are relatively untested, increased inspections might be appropriate. Monthly inspections of the treatment, storage and disinfection (dechlorination, if used) facilities, as well as discharge mechanisms or other in-wetland structures, are recommended for at least the first year of operation.

The first five alternatives all relate to hydraulic loading in some capacity, indicating its importance to a properly managed wetland-wastewater system. Alternatives 6 through 8 are management options reflecting natural wetland processes. To the extent possible, providing for the occurrence of natural processes and following natural cycles might reduce the O&M required in a wetland. The last two alternatives are non-natural processes, but they might be beneficial to a wetland receiving wastewater.

Table 7-2 lists these operation and maintenance options and a description of where these methods already have been used. Table 7-3 presents a general evaluation of these options. Other options are available, but these have been used and documented.

7.3.3 Operation and Maintenance Manual

To provide consistent and standardized procedures for operation, maintenance and replacement, a brief **OMR manual is recommended.** Several of the manual's benefits are listed below.

- A "blue print" for applicable O&M procedures is provided.
- The schedule for proposed O&M activities is established.
- The flexibility designed into the system can be described to assure use of the system's full potential.
- The party(ies) responsible for the discharge know what the operator is doing.
- New operators can understand past activities much more easily.
- The state regulatory agency can be aware of the discharger's wetlands management activities.

Such a manual can be part of the operation and maintenance manual for the wastewater treatment plant.

An OMR manual should provide direction for operating any facilities directly affecting the wetland including effluent treatment plant processes, storage facility, pipelines and other facilities within the wetland. The manual can include daily procedures, equipment, infrequent but periodic procedures and contingency plans in case specific occurrences arise. Table 7-4 lists typical items to include under each of these elements.

Table 7.2. O&M Options for Natural Wetland-Wastewater Systems (not including environmental monitoring techniques)

Option	Description	Example Locations Where Utilized	Perceived Effectiveness of Option
Periodic sediment removal within wetland	Dredging of fine sediment to promote infiltration to underlying soil.	Ponds in the Netherlands	Effective if water would move downward and underlying soil productivity is relatively high.
Use of certain vegetative species	Introduction and maintenance of species which promote assimilation with minimal ecologic distrubance	Calumet County, WI	Considered experimental; effectiveness is difficult to monitor if vegetation grows due to climatic and seasonal variations.
Harvesting (H) or burning (B) of vegetation	Removing accumulated biomass, spawning increased productivity.	H - Lake Buena Vista, FL; Hercules, CA; Hamilton, NJ; May River, Canada; other artificial systems B - Gainesville, FL (accidental); Arcata, CA (proposed)	Some nutrients are recirculated; however, wetland must adjust.
Nitrogen removal via control of wastewater inflow to wetland	Promotion of anaerobic conditions in a wetland (e.g., controlling inflow or channel deepening).	Lake Buena Vista, FL	Difficult to measure because waters released from wetland are dispersed; process is sensitive to environmental fluctuations.
Intermittent wastewater applications	Periodic reduction or avoidance of discharge to a wetland. The option usually includes wastewater storage, multiple cells, multiple discharge locations.	Bellaire, MI; Houghton Lake, MI; Drummond, WI; Hercules, CA; Cannon Beach, OR; Humboldt, Canada	Dependent upon when and to extent discharges are reduced.
Mosquito control	Multiple discharge locations. Chemical additions, biological controls or controlling water levels (via dredging or dikes)	Gainesville, FL; Lake Buena Vista, FL; Martinez, CA	Biological control (fish) at Martinez, CA has not been satisfactory to state officials (Stowell et al. 1981).
Avoiding shock loadings to wetland (in conjunction with use of storage)	Sediment traps, storage volume or use of a different method for disposing wastewater.	Fremont, CA (proposed)	Traps can store wastewater flows for up to 10 days. Different disposal methods may not be economical.

Table 7-3. Assessment of O&M Options for Natural Wetland-Wastewater Systems (not including environmental monitoring).[1]

Option	Principal Cost Factors	Impacts	Methods of Operation	Needs Prior to or During Implementation
Periodic sediment removal within wetland	Size of area to be dredged, frequency of dredging, site access from upland location.	Resuspension of some sediment and and disruption of bottom habitat.	Dredging equipment and operator in addition to wetland ecologist.	Depths of sediments to be dredged, size of dredged area, spoil disposal location(s), approval from wildlife officials and COE.
Introduction of certain vegetative species	Size of wetland area to be planted, availability of vegetation.	Variable depending upon success of use, size of affected area and type of vegetation. Could cause changes in wildlife.	Botanist to monitor growth, water quality and ecological monitoring.	Method for introducing seeds or plants; knowledge of optimal environmental characteristics; approval by state wildlife officials.
Harvesting or burning of vegetation	Size of wetland area, needs for controlling fire, and accessibility of affected wetland area.	Decreased vegetation diversity and disruption of wildlife habitat and flow patterns, at least temporarily.	Low-water conditions and structural controls (e.g., trenches surrounding area).	State approval, fire control measures and assessment of wetland ignitability.
Nitrogen removal via control of wastewater flow to wetland	Provision of either storage facilities or alternative disposal method for water flow control.	Disruption of ecology following channel dredging, potential impacts on vegetation.	Dredging equipment, operator and wetland ecologist for channel deepening; operating rules for inflow control.	Approval for channel deepening by state and Corps of Engineers.
Intermittent wastewater applications	Storage capacity or number of discharge locations (Table 6-3) and their distance.	Generally beneficial due to reduced stress of wastewater on wetland site. Allows dry periods and may be best method for following normal hydroperiod.	Operating rules for when and to what extent discharge is altered. Consult with state wildlife officials.	Storage or an acceptable alternative method for disposing wastewater is needed.
Mosquito control	Wetland size, chemical or fish availability, access to portions of wetland.	Water quality is adversely altered if chemicals are utilized. Ecology can be adversely altered by controlling water levels.	Water quality and ecological monitoring in addition to chemical additions, fish monitoring or water level controls.	Assess need for control vs. feasibility of each available method. Consult with state or federal wetland scientists.
Avoid shock loadings to wetland	Design flow, land availability for storage, location for different disposal.	Could significantly alter wetland vegetation and wildlife if persistent or if shock load contains toxics.	Operating rules for when and to what extent discharge to wetland is altered. Consult with state wildlife officials. Sediment traps would need to be cleaned periodically.	Amount of storage volume, size of trap, or design of alternative disposal method. State environmental agency approval is needed for any alternative disposal method.

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(1) See Table 7-2 for a brief description of each option.

Table 7-4. Potential Elements of an OMR Manual for a Wetland-Wastewater System

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A. Daily Procedures

- Visual inspection of effluent
- Flow monitoring
- Recording inflows from industries
- Managing stored water volumes
- Visual inspection of the wetland for stress indicators

B. Equipment Needs

- Lightweight, wade-tracked "Mud-Cat" bulldozer (for excavating wetland soils)
- Site access vehicle

C. Operation Plans and Periodic Maintenance Procedures

- Matching discharge schedules with system response
- Equipment maintenance procedures
- Periods of time during the year to avoid certain activities
- Re-evaluation of operating rule for storage facility
- Re-evaluation of disinfectant dosage
- Effluent monitoring (based on NPDES permit)
- Wetland monitoring (see Section 7.4)
- Preventive maintenance
- Altering location of discharge within the wetland
- Intermittent application procedure

D. Management Plan

- Planting of vegetation
- Harvesting schedule
- Burning schedule

E. Contingency Plan

- In case secondary treatment is not achieved (for example, a back-up disposal method)
- In case of extreme weather conditions
- In case of peak contributions from industries
- In case average flows increase substantially over a period of a few years (for example, revise the system design)

Table 7-5 lists the elements of NPDES Permit Compliance that also should be addressed by the manual.

An OMR Manual for a wetland-wastewater system should be periodically reviewed and revised as the wetland ecology is better understood, as development around the wetland occurs and as regulations may change. Many factors affect performance of a wetland; these are incorporated into design of the system. As these factors change, however, OMR activities should be reassessed. The two main sections of the wetlands OMR manual are operation and management. Maintenance and repair or replacement will be determined primarily by the specifications of the equipment being used. The major maintenance tasks for wetlands discharges are for storage facilities, disinfection, transmission to the wetland and discharge ports. Management options introduced also will require maintenance.

Operation Plan. An operation plan should be developed and tested to maximize the full potential of the wetland system as it starts up and as it continues to operate. The operation plan must be responsive to changing wastewater flow volumes and wastewater quality, as well as changing conditions in the wetland. To be responsive, the operation plan depends on feedback from the post-discharge monitoring system (see Section 7.5).

The major components of an operation plan for a wetland-wastewater system relate to the 1) method, 2) frequency and 3) quantity of wastewater discharged to the wetland. If there are multiple discharge points within a wetland or multiple wetland cells, the number of operation combinations increases. The engineer should prepare a detailed valve diagram to describe how each flow pattern available within the system is achieved (See Figure 7-4). Also, these system flow patterns should be related to the natural seasonal variations in the wetland.

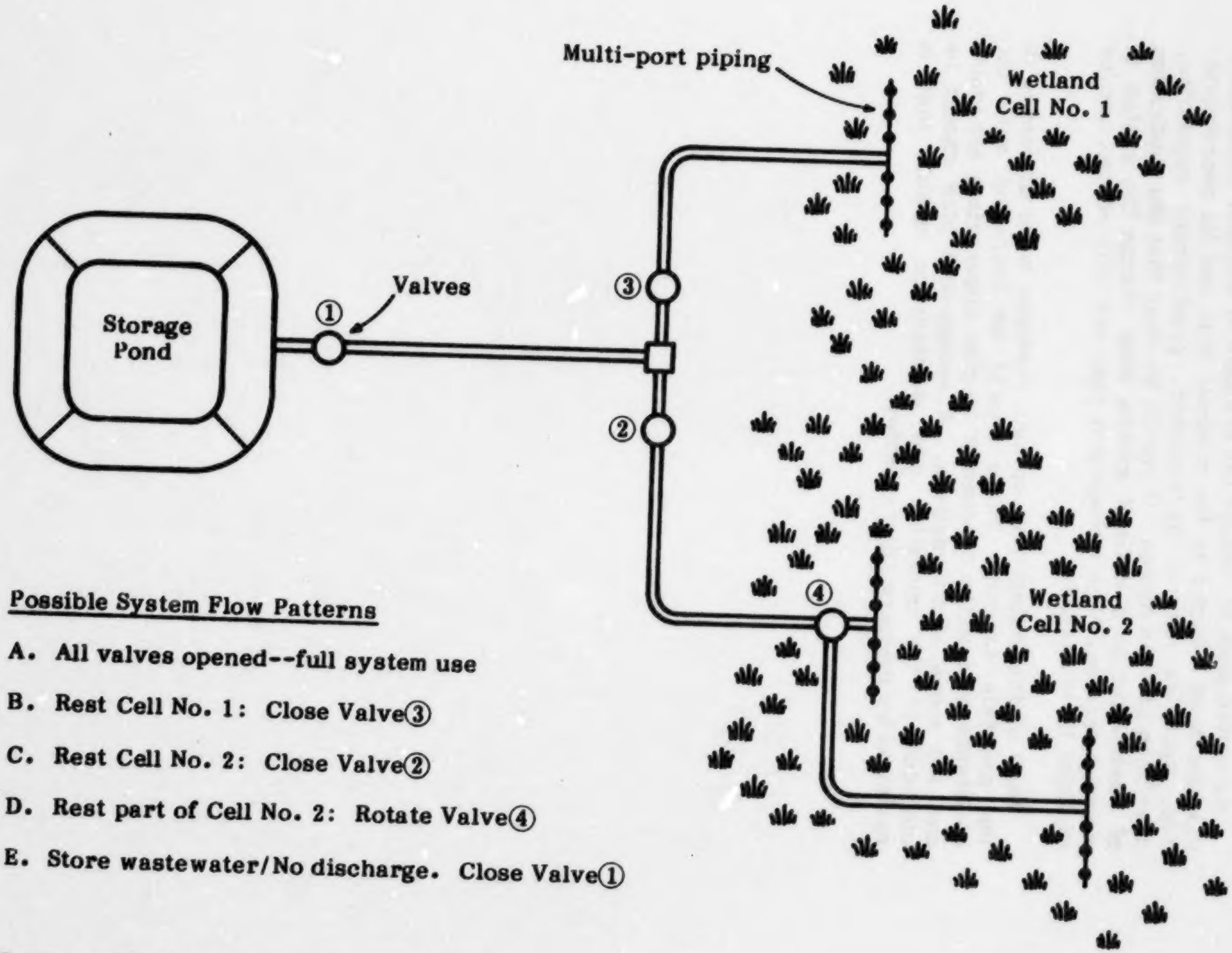
Management Plan. A wetland-wastewater system differs from other wastewater management systems in several ways: vegetation cycles, changes in types of vegetation, organic and nutrient cycling and variations in flow patterns within the wetland. In addition to inherent changing conditions of a wetland, many changes can result from the application of wastewater. Given this constantly changing system, the user of the wetland can choose to allow the wetland to respond naturally (self-management) or to develop a management plan providing more control over some of the changing wetland conditions.

If the wetland shows little or no signs of stress, the self-organizing ability of the wetland is the best management option. **Signs of stress** can be observed and measured by gross production of biomass and total ecosystem consumption (Odum 1978). Changing vegetation, wildlife losses, accumulation of

Table 7-5 Elements of NPDES Permit Compliance

General	Effluent Characteristics	Records and Reports
Permit expiration date	Concentrations or loadings for each parameter (minimum, maximum)	Sample times and locations
Outfall locations	Flow measurements	Lab analyses times and locations
Date of last inspection		Analytical methods
Description of special permit requirements, if any		History of records
		Equipment calibration
		Facility operating records
		Quality assurance records
		Sources of wastewaters

Permit Verification	Operation and Maintenance	Self Monitoring
Facility description	Standby power	Flow measurements
Treatment process descriptions	Alarm system	Sampling locations and frequencies
	Sludge disposal	
Notification of revised flows or quality	Qualified Staff	Sample collection and transport
	Availability of consulting engineer	Laboratory methods
Number and location of outfalls	Training procedures	Laboratory certification
	Parts and equipment file	Instrument calibration
	Operating instructions file	Receiving water observations and monitoring (as required)
	Operation and maintenance manual	
	Treatment by-passing	
	Treatment overloads	
	Monitoring	


Multi-port piping
Wetland Cell No. 1
Storage Pond
Valves
①
③
②
④
Wetland Cell No. 2

Possible System Flow Patterns

A. All valves opened--full system use

B. Rest Cell No. 1: Close Valve③

C. Rest Cell No. 2: Close Valve②

D. Rest part of Cell No. 2: Rotate Valve④

E. Store wastewater/No discharge. Close Valve①

Source: CTA Environmental, Inc. 1985.

Figure 7-4. Example Flow Pattern Diagram

organic material, algal blooms, stunted tree growth and reduced vegetative reproduction also can indicate stress on the system.

An active plan to manage the changes in wetland-wastewater systems must respond to the wetland type and its characteristics, such as natural hydroperiod, predominant vegetation, dry-down or burn cycles. It should be clear that **the application of wastewater to a wetland system does change the system** to varying degrees. The management plan can help control and/or minimize those changes.

Some of the management options available were discussed in the previous section. These should be evaluated with the assistance of a wetland scientist to plan appropriate schedules and the scope of alternatives. A management plan should be included in the operation and maintenance manual that is reviewed by the permitting agencies.

7.4 MITIGATION OF WETLAND IMPACTS

One of the goals of this Handbook is to present the potential use of wetlands for wastewater management in the context of wetlands maintenance and protection. Ultimately, this assumes that wetlands can be used for wastewater management while maintaining basic wetlands functions, with the understanding that some changes will occur. Only those systems that can accept properly applied wastewater without detrimental effects to basic processes should be used. The use of some systems under some conditions should be avoided.

The mitigation of impacts is a primary concern of using wetlands for wastewater management and a fundamental component of this Handbook. Procedures for selecting an acceptable site are based on reducing the potential for wetlands impacts. Discharge limits proposed are those that have been used with apparent reduction of wetlands impacts. Conservative limits have been presented for critical loading parameters when the uncertainty of impacts is greater. Engineering, construction and O&M options discussed all have mitigation of impacts as their basis.

Mitigation is integrated throughout this Handbook. Table 7-6 summarizes important mitigation practices for wetlands site screening and engineering planning. Table 7-7 lists important construction and O&M mitigative measures.

Nelson and Weller (1984) summarized a series of variables that can further affect mitigation and the magnitude of impacts. The four major variables are:

1. Operations variables
   - Distribution, scale and type of activity
   - Frequency, duration and season of activity
   - Location of activity within an ecosystem
2. Physical and chemical variables
   - Hydrologic regime and flow dynamics
   - Particulate composition of soil and sediments
   - Chemical composition of water and sediments
3. Biological and ecological variables
   - Habitat diversity and carrying capacity
   - Population abundance, diversity and productivity
   - Ecosystem stability, resistance and resilience
   - Presence of key species important to an ecosystem

4. Public interest variables
   - Regional scarcity of affected habitat types
   - Abundance of sport and commercial populations
   - Presence of protected species

While this is not an all inclusive list and some of these variables may be difficult to measure, it does provide insight into the types of characteristics which can influence the severity of impacts and that should be incorporated into system design and operation.

Table 7-6. Mitigation Measures for Site Screening/Engineering Planning.

1. Selection of unique or endangered wetlands is discouraged.
2. Use of conservative hydraulic rates is recommended.
3. Discharges into a wetland should follow natural hydroperiod as much as possible.
4. Upstream diversions or retention ponds might be used for reducing excessive sediment input from developing areas within the watershed.
5. Pretreatment should be conducted to remove trace metals and toxics from influent to treatment plant.
6. Removal of phosphorus within the treatment facility should be considered for wetlands discharges with phosphorus sensitive downstream waters.
7. Discharge points should be varied to improve assimilation and maintain hydroperiod.
8. Discharge mechanisms should be used which prevent erosion or channelization of wetland.

Source: Adapted from Nelson and Weller. 1984.

Table 7-7. Mitigative Measures for Construction and O&M

1. The top and outside bank of dikes should be vegetated.
2. A vegetative buffer strip should be used at the outer limits of construction to stabilize the soil surface.
3. Wetland crossings should be built on elevated structures that preserve natural drainage patterns; pilings are better than fill to ensure passage of water, nutrients and organisms.
4. Banks and disturbed upland slopes should be stabilized with vegetation.
5. Construction should be timed to avoid breeding, spawning and nesting seasons, and to coincide with low flows.
6. Clearing of vegetation for construction should be restricted.
7. Exposed soil should be protected through revegetation, mulching or filter cloth.
8. Alternate routes around wetlands should be employed for pipeline crossings when possible.
9. Existing access trails, natural corridors, pipeline rights-of-way and ditches should be used where possible.
10. Heavy equipment should be operated atop mats or barges (where feasible).
11. Pipeline ditches should be backfilled as near as practicable to the original marsh elevation with original dredged material.
12. Pipeline corridors and other disturbed sites should be revegetated with wildlife food and cover crops that also prevent erosion.

Source: Adapted from Nelson and Weller. 1984.

7.5 POST-DISCHARGE MONITORING

All discharges to waters of the U.S. require monitoring the effluent quality. Sometimes additional monitoring in the receiving water is required as well under thee NPDES Permit program. Chapter 3 discusses, from a regulatory perspective, the need to monitor wetlands discharges carefully to assess impacts and long-term viability of the wetland. This requires not only monitoring the effluent, but also the conditions within the wetland.

Few pre- or post-discharge monitoring programs have been implemented on wetlands used for wastewater management. As such, a joint effort between the community and the regulatory agencies may be required until more data are collected on the response of various wetlands to wastewater discharges. Joint efforts in obtaining required data could be advantageous to both parties, given the variety of data requirements needed to assess a wetlands discharge.

Most monitoring projects to date have been research-related. The scope of these studies probably is not practical for smaller communities with limited funds. However, these programs do provide an indication of the major parameters and general sampling design applicable to a wetlands discharge. A few monitoring programs have been conducted by utility authorities using wetland wastewater systems, and these programs provide additional insights into the type of sampling programs that may be reasonable for a community to undertake.

The regulatory program requiring post-discharge monitoring is the NPDES Permit program, through permit conditions and/or compliance requirements. The objectives of monitoring wetlands discharges include:

- Assuring maintenance of water quality standards and attainment of effluent limitations.
- Assessing a wetland's ability to transport or assimilate wastewater on a long-term basis. This incorporates assessment of organic, nutrient and metal uptake by soils and vegetation.
- Determining discharge impacts on wetlands ecology, including changes in vegetation or wildlife assemblages.
- Evaluating viral contamination and potential disease vectors. If chlorination is used, potential adverse effects of chlorinated compounds should be assessed.

The objectives of wetlands-wastewater systems vary from one system to another. Regardless of system specific objectives (e.g., nutrient removal or disposal only), all wetlands discharges must have **wetlands maintenance** as an objective. This should be the minimum criterion in selecting monitoring parameters.

Chapter 3 presented the concept of a tiered approach to assessing and potentially permitting a wetlands discharge. If conservative loadings to an acceptable site are used, the scope of the evaluation process would be less than for higher loadings or the proposed use of a sensitive or endangered wetland area. The same approach is applicable to post-discharge monitoring. Actually, the required monitoring would be related to the parameters evaluated in site-screening, the permit application and in establishing effluent limitations.

As the design of the post-discharge monitoring program is considered, the spatial and temporal sampling features described in Section 9.2 should be reviewed. Regardless of the scope of the monitoring program, these features should be incorporated into program design. Since the detailed site screening provides the background information for comparison with post-discharge monitoring data, its design will be an integral part of the post-discharge monitoring program.

Based on a tiered approach, Table 7-8 lists the parameters that should be assessed initially for **any** discharge. The applicable water quality standards (uses and criteria) and effluent limitations could modify this general listing. Some parameters may be deleted following sufficient demonstration that they are not significant. Further, the frequency of sampling certain parameters might be altered depending on wastewater characteristics and concentrations observed in the wetland.

Table 7-8. Post-Discharge Monitoring Components and Frequency of Sampling - Tier 1 Analyses.

Geomorphology	
None	
Hydrology	
Wastewater flow	- metered, continuous
Water depth	- weekly
Surface water flow	- monthly (with water quality sampling)
Water Quality (surface waters)	
Dissolved oxygen	- monthly, diurnals
BOD	- monthly
Suspended solids	- monthly
pH	- monthly
Water temperature	- monthly
Fecal coliforms	- monthly
Treatment plant effluent	- monthly
Ecology	
Visible stress, change in growth patterns or nuisance conditions	- monthly

The parameters listed in Table 7-8 would be required of a Type 2 discharge as well as Type 1 discharge. Other analyses required of a Type 2 discharge would be dependent on several elements, including:

1. Wastewater management objectives (e.g., nutrient removal)
2. Scope of detailed site-screening/site-specific effluent limitation assessments
3. Effluent quality (nutrient levels, industrial component)
4. Type of wetland (water level or pH sensitive).

Permit conditions and performance criteria, based on water quality standards, would be the basis for additional analyses. Table 7-9 lists parameters that could be considered or required for more detailed analyses based on the elements listed above. The suggested frequencies of sampling also could be affected by these elements. Also, all of the parameters listed would not necessarily be required of each discharge.

If the existing data base is limited or nonexistent, **monitoring prior to initiation of the discharge is highly recommended,** regardless of the size of the discharge. Post-monitoring data will be of significantly less value without documentation of background conditions. Ideally, premonitoring should occur during different seasonal and flow conditions. If not possible, a thorough survey of each post-discharge monitoring parameter should be conducted based on the time and/or funds available. Emphasis should be given to certain parameters varying on a diurnal basis (e.g., dissolved oxygen) and other parameters varying with flow.

Suggestions for the location, frequency and duration of sampling are discussed in Section 9.2, as well as the need for monitoring wells, weirs or other sampling mechanisms. The regulatory agency responsible for compliance monitoring should inspect each wetland discharge once a year to monitor wetland changes and assess current reporting and monitoring requirements.

Table 7-9. Potential Post-Discharge Monitoring and Sampling Frequencies - Tier 2 Analyses

Geomorphology	
Sediment accumulation	- Semiannually
Changes in watershed (e.g., due to development, other uses)	- Semiannually
Hydrology	
Water budget, residence time	- With any major change of inflows
Precipitation	- Daily
Water Quality	
(surface waters)	
Nitrate (NO_3)	- Quarterly; different seasons
Un-ionized ammonia (primarily for non-acidic waters)	- Quarterly; different seasons
Total nitrogen (TN)	- Quarterly; different seasons
Orthophosphate (PO_4)	- Quarterly; different seasons
Total phosphorus (TP)	- Quarterly; different seasons
Total coliforms	- Quarterly; different seasons
Fecal Streptococci	- Quarterly; different seasons
TOC	- Quarterly; different seasons
COD	- Quarterly; different seasons
Chlorine residual	- Quarterly; different seasons
Chloride	- Quarterly; different seasons
Metals (lead, iron, mercury, cadmium, etc.)	- Quarterly; different seasons
Biocides	- Quarterly; different seasons
Nutrient budget	- With any major change of inflows
(ground waters)	
Nitrate (NO_3)	- Quarterly; different seasons
Fecal coliforms	- Quarterly; different seasons
Chloride	- Quarterly; different seasons
Biocides	- Quarterly; different seasons
Metals	- Quarterly; different seasons
Ecology[1]	
Vegetation species composition	- Semiannually; growing seasons
Vegetative diversity	- Semiannually; growing seasons
Relative abundance	- Semiannually; different seasons
Wildlife surveys	- Semiannually; different seasons
Productivity	- Semiannually; different seasons
Litter fall	- Semiannually; different seasons
Benthic macroinvertebrates	- Semiannually; pre/post emergence
Insect populations (mosquitoes)	- Semiannually; different seasons

---

[1] Most sampling early and late in the growing season; non-growing season data also would be valuable for most components.

7.6 USER'S GUIDE

Chapter 7 discusses the three basic steps that follow engineering planning and design, leading to project implementation:

1. Construction and installation - See Section 7.2.
2. Operation, maintenance and repair (OMR) - See Section 7.3.
3. Post-discharge Monitoring - See Section 7.4

The wetland-specific topics and issues discussed in this chapter are those that should be addressed for any wetlands-wastewater system, in addition to the typical procedures conducted for any wastewater treatment facility. Figure 7-5 shows the relationship of construction and O&M to the decision making process.

Chapter 6 provides guidance on the type of considerations that must be examined in planning and designing a wetlands-wastewater system. Chapter 7 incorporates these design decisions into the installation/construction, O&M and post-discharge monitoring programs. Design decisions from Chapter 6 determine construction and O&M requirements. How they are accomplished is a primary purpose of Chapter 7.

Figure 7-6 illustrates the process of putting a facility on-line, from the point of having design plans and specifications approved, and a NPDES discharge permit issued. It is assumed that if this user's guide is being employed, design plans and specifications have been approved and an NPDES permit issued. Preparation of the O&M Manual and the post-discharge monitoring program should begin in the engineering design phase and be finalized before construction is complete.

Form 7-A outlines the types of questions that should be addressed at the pre-construction conference. The construction elements should be thoroughly planned before construction is begun. The O&M and monitoring sections of Form 7-A should be conducted in conjunction with preparation of the O&M manual. These elements are essential to operating the plant properly, assessing wetland impacts and, in essence, protecting the wetland. As a result, O&M and monitoring should be planned, reviewed and approved prior to issuance of the NPDES permit. Some O&M and monitoring elements may be enforced as permit conditions.

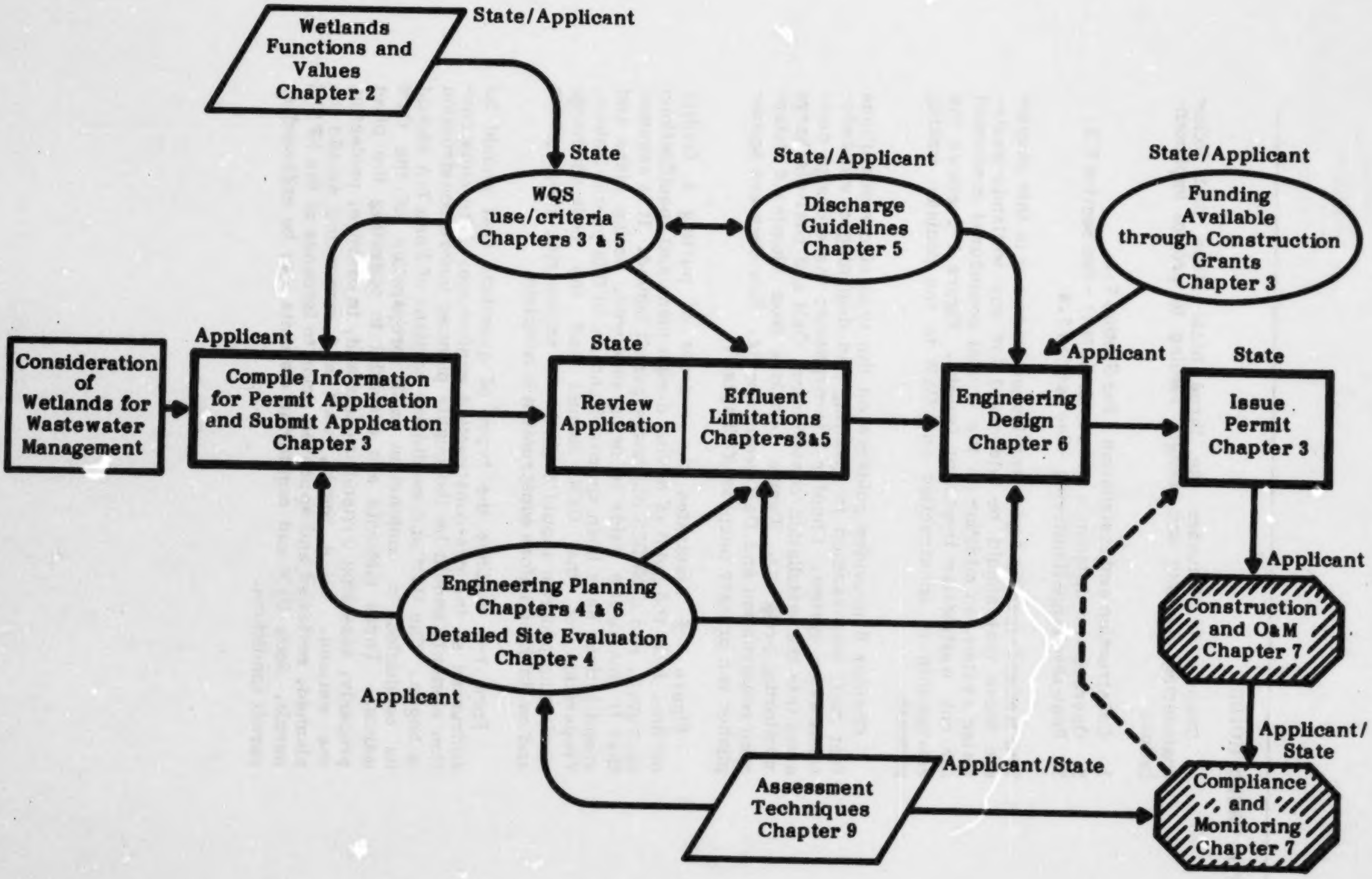

Wetlands Functions and Values Chapter 2
State/Applicant
State
WQS use/criteria Chapters 3 & 5
State/Applicant
Discharge Guidelines Chapter 5
State/Applicant
Funding Available through Construction Grants Chapter 3
Consideration of Wetlands for Wastewater Management
Applicant
Compile Information for Permit Application and Submit Application Chapter 3
State
Review Application
Effluent Limitations Chapters 3&5
Applicant
Engineering Design Chapter 6
State
Issue Permit Chapter 3
Applicant
Construction and O&M Chapter 7
Applicant/State
Compliance and Monitoring Chapter 7
Engineering Planning Chapters 4 & 6
Detailed Site Evaluation Chapter 4
Applicant
Assessment Techniques Chapter 9
Applicant/State

Figure 7-5. Relationship of the Handbook to the Decision Making Process.

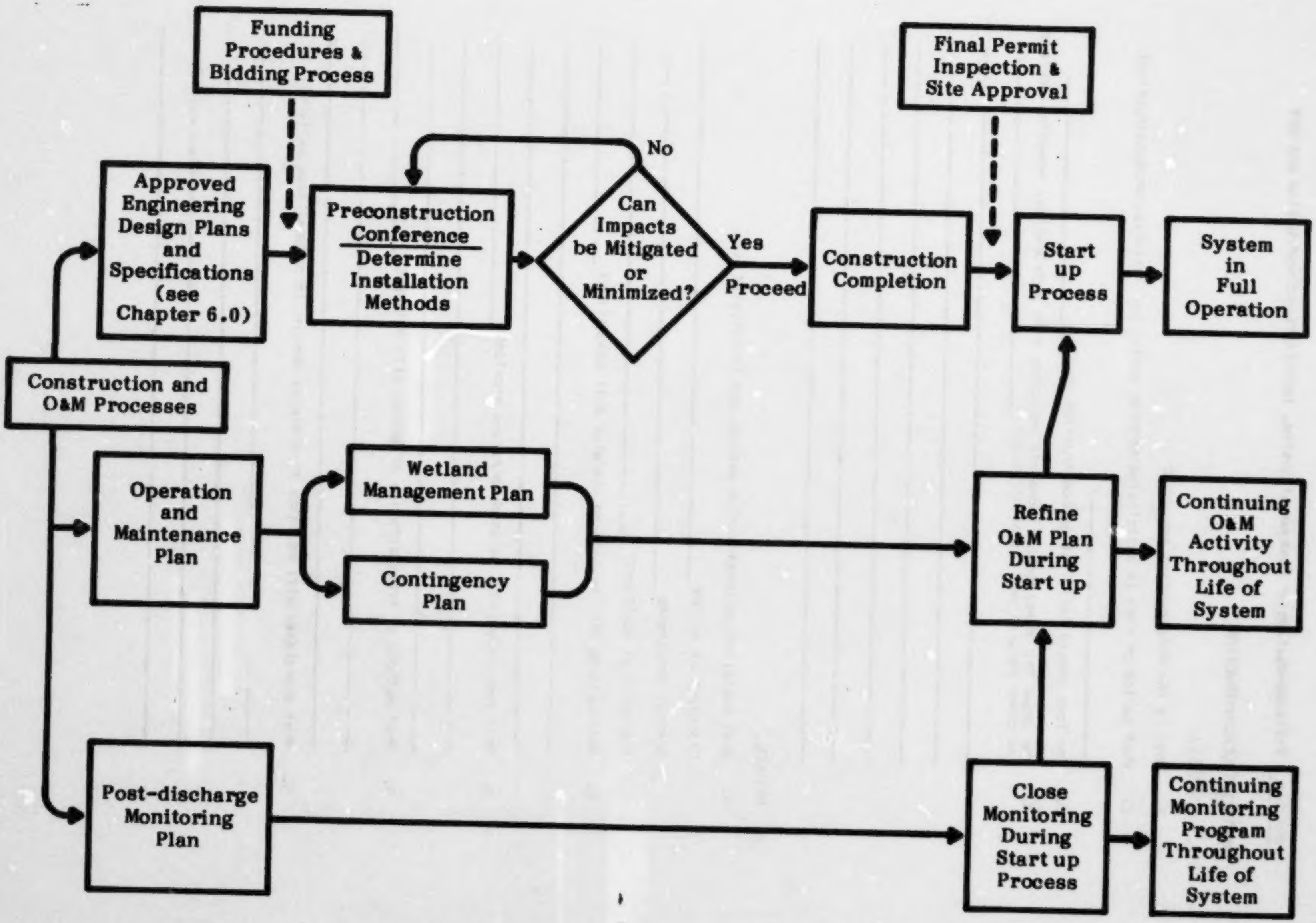

Funding Procedures & Bidding Process
Approved Engineering Design Plans and Specifications (see Chapter 6.0)
Preconstruction Conference
Determine Installation Methods
Can Impacts be Mitigated or Minimized?
No
Yes
Proceed
Construction Completion
Final Permit Inspection & Site Approval
Start up Process
System in Full Operation
Construction and O&M Processes
Operation and Maintenance Plan
Wetland Management Plan
Contingency Plan
Refine O&M Plan During Start up
Continuing O&M Activity Throughout Life of System
Post-discharge Monitoring Plan
Close Monitoring During Start up Process
Continuing Monitoring Program Throughout Life of System

Figure 7-6. Process Flow Chart and Decision Diagram for Construction and O&M.

FORM 7-A. Wetlands-Wastewater Management System, Installation/Construction and O&M

INSTALLATION/CONSTRUCTION

A. SCHEDULES.

1. What is the construction schedule?
2. What period of time is anticipated between design and installation/construction?
3. How long should installation/construction take?
4. How does the construction schedule coincide with hydroperiod, breeding periods and other natural wetland occurrences?

B. METHODS.

1. What installation/construction methods are anticipated for:
   Distribution system
   Control structures
   Placement of equipment
2. What methods will be used to minimize soil compaction?
3. What techniques will be used to reduce erosion?
4. What methods of transportation or access will be used?
5. What approaches will be taken to minimize changes in natural flow patterns?

FORM 7-A Continued

OPERATION & MAINTENANCE

A. SCHEDULE.

1. What is the anticipated flow schedule to the wetland?

Continuous ______________

Intermittent ______________

Seasonal ______________

2. What plans will be implemented to minimize changes to natural hydroperiod?

____

____

3. Are resting periods anticipated for the wetland? Yes ______ No ______

If yes, when will they occur? Regularly ______ Seasonally ______

4. What period of time is anticipated between construction and initiating wastewater flows to the wetland?

____

____

B. SYSTEM COMPONENTS.

1. Distribution System

a) How often will discharge port(s) be checked and/or flushed?

____

b) How often will the area around the discharge point(s) be checked for excessive erosion? ______________

2. Vegetation

a) Is planting of vegetation incorporated into system design? Yes ____ No ____

b) Is harvesting of vegetation planned? Yes ______ No ______

If yes, will selective harvesting or replanting be done? ______________

If replanting, what will be the source and type of vegetation for replanting?

Source ______________________________

Type ______________________________

c) How often will the wetlands water surface be checked for excessive build-up of floating vegetation or algae? ______________

d) What practices are anticipated at what frequency for maintaining the planned amount of open water?

____

____

3. Other (as specified by Regulatory Agency)

____

____

4. What routine O&M will be done on equipment or other structural aspects of the Wetlands-wastewater system?

____

FORM 7-B. Wetlands Wastewater Management System, Post-Discharge Monitoring

1. Did compilation of the NPDES permit application require any primary source data collection?

   Yes ______ No ______

   If yes, what data were collected: (Hydrology, water quality, ecology and soils)

Parameter	Frequency	Number of Samples

2. Was pre-discharge monitoring required?

   Yes ______ No ______

   If yes, what data were collected: (Hydrology, water quality, ecology and soils)

Parameter	Frequency	Number of Samples

3. What are the potential sources of existing data for the wetland or watershed? Do existing background data exist?

   ____

   ____

   ____

   Yes ______ No ______

   If yes, what data were collected: (Hydrology, water quality, ecology and soils)

Parameter	Frequency	Number of Samples

What do data indicate about:

Existing water quality? ______________________________

____

____

Assimilative capability of soils or vegetation? ______________________________

____

____

FORM 7-B Continued

Hydrologic sensitivity? ______________________________

____

____

Ecological stability? ______________________________

____

____

Others ______________________________

____

____

____

4. What are monitoring requirements established by the NPDES Permit?

Parameter	Location	Frequency	Method

5. Has a plan been established to monitor wetland changes?

Hydroperiod? Yes ____ No ____

Vegetation composition? Yes ____ No ____

Tree growth? Yes ____ No ____

Water chemistry?

pH Yes ____ No ____

DO Yes ____ No ____

Fecal coliforms? Yes ____ No ____

Nutrients Yes ____ No ____

Others?

____

____

____

____

____

____

FORM 7-B Continued

6. Describe the components of the proposed monitoring program (see Section 9.2 for assistance).

	Parameter	Location	Frequency/Duration	Methods
Surface Waters				
Groundwaters				
Soils				
Ecology				

Responses to the first five questions will form the basis for designing the post-discharge monitoring program.

8.0 WETLAND RESPONSE TO WASTEWATER LOADING

8.1 RELATIONSHIP TO PLANNING AND DESIGN 8-2

8.2 IMPACTS TO WETLANDS FUNCTIONS AND VALUES 8-6

- **8.2.1 Hydrology**
- **8.2.2 Water Quality**
  - o Organics
  - o Nutrients
  - o Metals
  - o Public Health
- **8.2.3 Ecology**
  - o Vegetation
  - o Wildlife

8.3 IMPACTS TO WETLAND TYPES 8-18

8.4 UNCERTAINTY AND RISK 8-20

8.0 WETLAND RESPONSE TO WASTEWATER LOADING

Who should read this chapter? Anyone involved with planning, designing or implementing a wetlands-wastewater discharge.

What are some of the issues addressed by this chapter?

- How do wastewater additions affect wetland functions and values?
- How do certain wetland types respond to wastewater discharges?
- What are the uncertainties and risks associated with a wetlands-wastewater system?

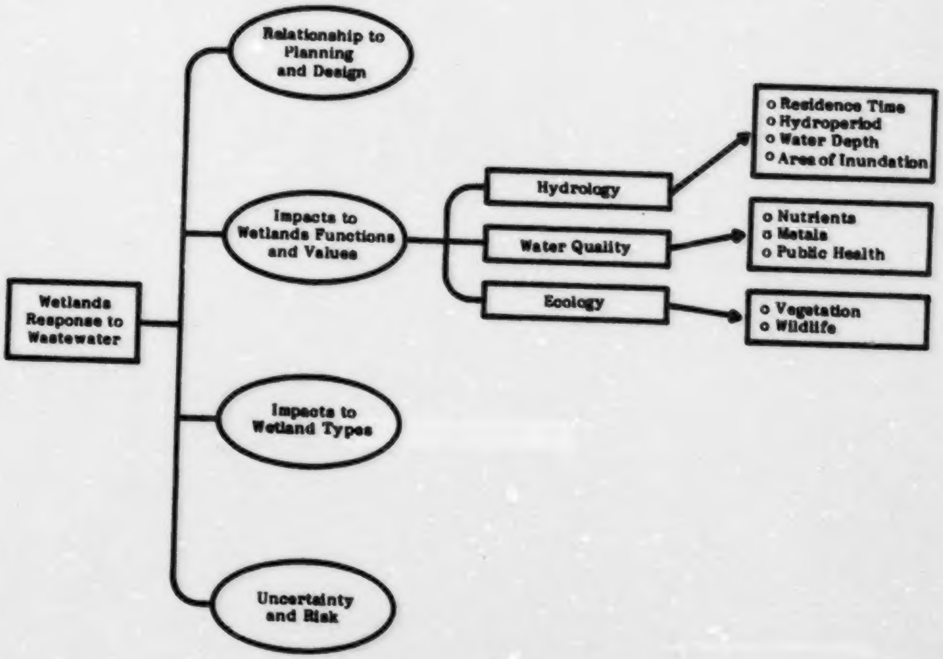

Relationship to Planning and Design
Wetlands Response to Wastewater
Impacts to Wetlands Functions and Values
Hydrology
Water Quality
Ecology
o Residence Time
o Hydroperiod
o Water Depth
o Area of Inundation
o Nutrients
o Metals
o Public Health
o Vegetation
o Wildlife
Impacts to Wetland Types
Uncertainty and Risk

Figure 8-1. Wetlands Response to Wastewater.

8.1 RELATIONSHIP TO PLANNING AND DESIGN

Changes occur in a wetland as a result of wastewater discharges or other management practices. It is important to understand the potential changes resulting from wastewater additions if wetlands discharges are to be well planned and managed. More importantly, the information presented in this chapter (summarized in Figure 8-1) concerning wetlands response and sensitivity to wastewater is essential to site screening and evaluation. The use of wetlands particularly sensitive to hydraulic or water chemistry alterations should be avoided. Since the engineering design process is intended to optimize both wastewater assimilation and wetlands protection, information concerning wetlands responses and sensitivity is an integral part of decision making. Table 8-1 summarizes the relationship of wastewater loadings to wetlands functions and values.

Table 8-1. Relationship of Wastewater Additions to Wetlands Functions and Values

Component	Areas of Importance	Functional Role and Importance
Geomorphology -Geology	Karstic Areas	Groundwater interactions in limestone areas uncertain; pose potential benefits (recharge) and hazards (contamination).
	Drainage Basin Characteristics - form	Areas of high topographic relief create potential for strong flood pulses resulting in undesirable flushing of effluent out of wetland without treatment.
	Drainage Basin Characteristics - types	Carolina Bay and other formations have intrinsic scientific, cultural and hydrologic values which may be threatened by wastewater application.
-Soils	Organic Soils	Nutrient retention potential low, permeability may also be low.
	Mineral Soils	High nutrient retention potential, permeability may be low. Clay pan impermeability protects groundwater resources but may impede surface water loading capacity.
Hydrology -Budget	Precipitation Component	Limits loading rates of wastewater.
	Groundwater Component	Groundwater discharge area places limits on loading rates of wastewater. Groundwater recharge area may prohibit wastewater application if effluent quality is poor and detrimental impacts are expected.
	Surface water/Runoff Component	Sources, rates and timing of inflow critical to maintaining wetland vegetation, detrital sediment and nutrient loading. Outflow characteristics define seasonal pattern of surface water storages, location of outflow may limit acceptability of wastewater application.
-Inundation	Frequency and Duration	Dominant force in shaping distribution and character of wetland vegetation. Changes in catchment size and shape, antecedant moisture and watershed topography will alter flooding characteristics.
-Infiltration	Capacity of Vertical Water Movement	Infiltration capacity important in determining loading rates, treatment capacity and efficiency.
-Flooding Effects	Nutrient Import/Export	Major source of nutrients for some wetlands, and downstream ecosystems may be dependent on wetlands exports for nutrients and food supply.
	Buffer Capacity	Wetlands have value as regional flood buffering devices and aid in low-flow augmentation. Wastewater addition may lower this hydrologic buffering capacity.
-Evapotranspiration		Not important unless drastic ecosystem alteration takes place. Wastewater may increase evapotranspiration.

Table 8-1. Continued.

Component	Areas of Importance	Functional Role and Importance
Water Quality -Chemical	Dissolved Oxygen	Plant and fish life tolerate low DO; but zero DO is detrimental. Controls type of microbial respiration and organic matter degradation.
	pH	Some plants present (*Sphagnum*) depend on low pH. Nutrient and metals release from sediments is pH dependent. Wastewater addition may increase pH, and carbonate buffering capacity.
	Nutrients	Nutrient cycles need to be balanced for proper ecosystem production. Productivity may be limited by nutrient availability. Nutrient exports by open wetland ecosystems create important links to downstream ecosystems.
	Metals/Toxins/Refractory Organics	Direct - acute and chronic effects from exposure to detrimental concentrations Indirect - bioaccumulation.
-Physical	Turbidity/Suspended Solids	Important source of particulate organic matter. Sedimentation of these particles provides basis for sediments, detrital food chain.
	Temperature	Effluent extends growing season in cooler climates and may promote frost damage.
-Biological	Microbial Respiration	Breakdown of organic matter, nutrient cycles.
	Public Health Vectors	Maintain or increase reservoir of imported or endemic water or arthropod borne disease.
	Algae blooms	Odor, aesthetic, toxic producing nuisance.
	Increase in macrophytes	Short term, seasonal storage of nutrients, influences subcanopy ecology in swamp forests.
Ecology -Plant Ecology	Material Cycling	General ecosystem functioning; wastewater addition may possibly augment or create imbalance.
	Adaptations	Plants specialize to grow and successfully compete in wetlands; modifications in nutrient and hydrologic regimes may alter species assemblages.
	Fire Frequency	Fire is important in maintaining the character of some wetlands; continuous wastewater application may prevent necessary dry-down for fire to occur.
-Vegetative types	Dominant vegetation	Essential in determining community structure and productivity, habitat value, and influences water quality, surface water flows.
	Subdominant vegetation	Important in filling and creating specialized ecological niches.
-Succession	Community equilibrium	Necessary to maintain a stable and productive ecosystem.

Table 8-1. Continued.

Component	Areas of Importance	Functional Role and Importance
-Productivity	Rate of production and respiration	Controls nutrient uptake and storage capacity; determines quality and quantity of detritus and influences evapotranspiration values. Diurnal pattern may be of sufficient intensity to alter water quality parameters of DO and pH.
-Rare and endangered species/ ecosystems	Habitat loss - Species Maintenance Interference	The location, range and inherent scientific and cultural values of these ecotypes/species require that these genetic pools are maintained intact and in place.
-Habitat	Edge Effect/Niche Separation	Maintains trophic levels productivity for ecological balance.

Source: EPA 1983.

8.2 IMPACTS TO WETLANDS FUNCTIONS AND VALUES

To consider wetlands for wastewater management, analyses of wetland functions and values must be conducted. First, the type and extent of change that can occur in a wetland should be assessed. Second, the degree to which wetlands assimilate or renovate wastewater should be evaluated. Using wetlands for wastewater discharges is contingent upon the understanding of these issues. Figure 8-2 indicates some of the concerns related to the extent of acceptable change (see Chapter 3 also). Some changes that may lead to unacceptable conditions and that can serve as indicators of change are listed below (Schwartz 1985):

- Changes in species composition
- Nuisance growth of algae
- Alteration of organic accumulation rates
- Dissolution of organic soils
- Heavy metal accumulation in food chains
- Reduction in natural bacteria populations
- Presence of chlorinated hydrocarbons
- Net export of nutrients and suspended solids
- Groundwater contamination
- Indication of pathogen problem
- Damage to adjacent ecosystems
- Downstream eutrophication.

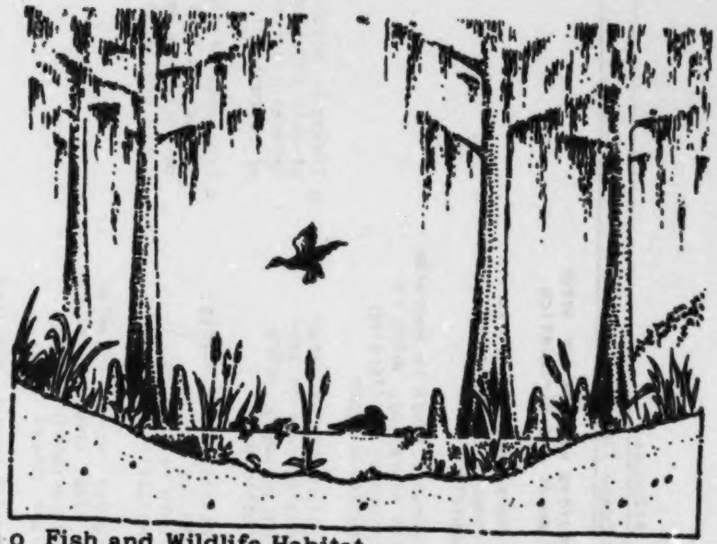
While the data base for understanding natural systems has increased, certain data limitations remain. Unfortunately, many wetlands systems have not been studied for their capacity to receive wastewater. The following sections summarize available information on impacts of wastewater discharges to the hydrology, water quality and ecology of a wetland.

8.2.1 Hydrology

The impacts of wastewater on wetland systems are interactive. Changes in hydrology, water chemistry and vegetation often are inseparable. Typically, however, impacts to the hydrologic regime of a wetland are most profound. Section 5.3 summarizes the importance of hydraulic variables in wetlands wastewater system design. Chan et al. (1980) summarized the responses of ecosystems to shifts in hydrologic regime related to velocity, renewal rate (residence time) and timing. Table 8-2 indicates the influence of hydrology on species composition, primary productivity, organic materials flux and nutrient cycling.

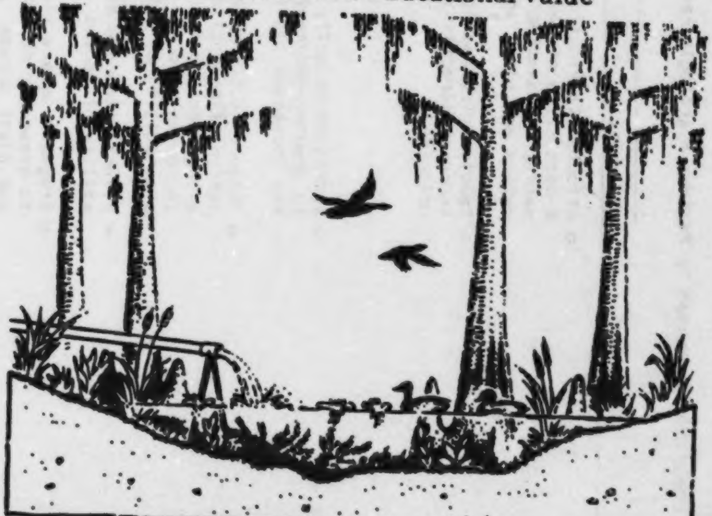
Excessive changes to the hydraulic loading of a wetland system can either convert the wetland to a different type of wetland or ecosystem, or severely damage the wetland to the point at which plant and animal assemblages are threatened.

Figure 8-2. Concerns Related to the Use of Natural Wetlands for Wastewater Management.



Wetland Functions and Values

- o Fish and Wildlife Habitat
- o Biomass Production/Silviculture
- o Flood Control and Storage
- o Erosion Control
- o Groundwater Storage
- o Water Quality Improvement
- o Aesthetic/Recreational/Educational Value



Wetland Responses to Wastewater

- o Increased Hydraulic Loading
- o Suspended Solids Filtration, Increase in Organic Sediments
- o Organics Reduction in Water Column
- o Nutrient Cycling/Removal
- o Wastewater Flow Detainment

Source: CTA Environmental, Inc. 1985.

Table 8-2. Wetland Ecosystem Responses to Various Hydrologic Factors.

Ecosystem Characteristics	Hydrologic Influences		
	Velocity	Residence Time	Timing
Species composition and richness	o Affects distribution & deposition of sediments, influencing elevation and plant zonation o Species richness found to increase directly with velocity	o Provides vehicle for water movement and circulation o Uniform mixing leads to monospecific stands of vegetation o Diversity tends to increase with elevation, which is influenced by flooding duration & depth	
Primary productivity	o Increased velocity related to greater sediment input and increased plant growth o "Edge-effect"--stimulation of production along channels due to increased velocity availability of water o Affects flow and availability of toxins o Stagnant waters linked to anaerobic conditions and plant stress o Dissolved oxygen related to velocity	o Availability of water seems to control lateral spread of ombrotrophic bogs o Availability of nutrients for plant growth related to availability of water o Regular renewal of water in tidal areas minimizes salt accumulation and plant stress o Regular renewal supplies O_2, minimizing stressful anaerobic conditions; depth & duration of flooding most important	o Timing or seasonality of rain input may affect lateral and vertical spread of ombrotrophic bogs o Frequency of flooding influences availability of toxins to wetland flora and fauna
Organic deposition and flux	o Rate of total particulate and total organic export directly proportional to flow rate (and velocity)	o Increased flow rate related to greater silt input and organic matter outflow	o Flooding frequency directly related to silt input and organic matter outflow o Soil organic concentration increases on gradient from actively flooded stream banks to less actively flooded inland high marshes
Nutrient cycling		o Influences mass loading, transport and flux of nutrients	o Nutrient flux related to timing of flooding with respect to plant growth cycle.

Source: Adapted from Chan et al. 1980.

Some wetland systems are more tolerant (wider range of water level change) than others; a bottomland hardwood is highly tolerant to flooding conditions. A study of flooding on trees in a bottomland hardwood system showed that trees apparently were unaffected by over 190 days of impoundment resulting from abnormally high reservoir levels (Carter et al. 1978). This study exemplifies the hydraulic flexibility of a bottomland hardwood wetland, but does not show the long range impact of regular prolonged flooded conditions. Teskey and Hinckley (1977) indicate impacts on trees not tolerant to flooding could be serious. Carter et al. (1978) also indicate that water tolerance of tree seeds and seedlings largely controls species distribution in relation to flooding.

Groundwater, surface area and soil pore space are the significant storage areas for water inputs to wetlands. Continuous wastewater addition would decrease the degree of seasonal fluctuations occurring in these storage reservoirs through uniform effluent application. Infiltration and percolation of effluent to groundwater depends on the physical components of the soil. Significant increases in surface water force changes in plant species composition and distribution which, in turn, may affect wildlife species abundance and diversity.

Velocity and depth are two other important hydraulic elements. The velocity of wastewater discharges can have detrimental impacts if it is great enough to undermine vegetation or cause erosion. Scour and sedimentation naturally occur in wetlands under different flow conditions but can be disruptive if they exceed natural levels or frequency of occurrence. The depth of water is associated closely with the hydroperiod of a wetland. Marked changes can result in species shifts and affect reproduction. Depth also can influence the dissolved oxygen levels and many processes related to dissolved oxygen concentration (e.g., metals releases, nitrogen releases to the atmosphere, etc.). The potential impacts of velocity and depth emphasize the importance of hydrologic conditions of a wetland.

8.2.2 Water Quality

The water quality impacts of wastewater loadings to wetlands pertain primarily to organics, nutrients, metals and public health. The impacts of biocides are not discussed in detail, since their primary sources are industrial effluent and runoff from agricultural lands.

Organics. The major concerns with organic loading to wetlands are: 1) excessive loadings of settleable organic matter, 2) excessive loadings of floating organic matter and 3) impacts to dissolved oxygen. Detrimental conditions can be avoided in most cases by providing secondary treatment and the accompanying reduction in solids and organic matter. Excessive buildup of bottom sediments and floating material has been noted by some studies (Ewel and Odum 1984), but these conditions can be avoided by more conservative loading rates (e.g., less than 1 inch/week) or improved BOD and solids removal by the treatment facilities. A well-functioning secondary treatment facility, in conjunction with appropriate hydraulic loading rates, should prevent excessive organic matter build-up. Nutrients associated with wastewater can enhance growth of algae or floating vegetation, however, leading to an increased oxygen demand. In this case, the hydraulic loading is important again. If normal wetland processes are not impacted adversly by excessive loadings, the organic and nutrient inputs from a secondary treatment facility are likely to be adequately assimilated by the wetland. These inputs and their effects should be monitored, since they are a indicator of wetland function.

Nutrients. Natural nutrient transformation processes enable many wetlands to assimilate and store increased levels of nutrients from wastewater sources. In wetlands managed for wastewater renovation, conditions which maximize nitrogen and phosphorus removal are important.

Nitrogen and phosphorus in domestic wastewater are present in several organic and inorganic forms. The natural nitrogen to phosphorus ratio of approximately 10:1 is frequently much lower (1:1 to 2:1) in domestic wastewaters, causing an excess in phosphorus for biological assimilation. This ratio varies with the source of sewage, and level and efficiency of pretreatment. The impacts of nutrients are minimized by maintaining a high quality (low nutrient) effluent. Wetlands have been shown (Sloey et al. 1978) to act as natural nutrient traps: some permanent (domes), and others on a seasonal or intermittent basis (tidal marshes, riverine swamps). The reported nutrient removal rates for those wetlands receiving sewage effluent indicate the wetland's capacity to assimilate nutrients above the natural levels.

The principal pathways by which nitrogen can be permanently removed from a wetland is by denitrification or by hydrologic export. Wetland hydraulics, e.g., residence time and depth, can affect the presence of anaerobic conditions (necessary for denitrification) and other nutrient removal processes. Other chemical processes which are important in nitrogen and phosphorus removal are co-precipitation and sorption reactions. These reactions are important in nitrogen and phosphorus retention in the soil profile. **The pathways for phosphorus and nitrogen removal are significantly different.** As a result, the ability of wetlands to retain phosphorus and nitrogen varies. For example, one wetland may remove nitrogen and phosphorus, whereas another wetland may remove only nitrogen.

Concern has been expressed over the ultimate retention capacity for nutrient storage. Several long term studies have given conflicting results. Florida sites have demonstrated long term assimilative capacity for nitrogen and phosphorus (Nessel 1978, Tuschal 1981), but a California site displayed a reduction in phosphorus removal efficiency (Whigham and Bayley 1979). The variability in nutrient retention or removal pertains primarily to phosphorus. Recent work by Richardson (1985) has indicated that the ability of wetlands to retain phosphorus depends on the content of extractable aluminum and iron, primarily the former. Further, Richardson indicates that although phosphorus retention may be observed during the first few years of application, eventual release of the stored phosphorus can occur. Some systems, as reported by McKim (1984), never retain significant quantities of phosphorus.

Craig and Kuenzler (1983) and Brinsen and Westall (1983) also have emphasized one of the views presented by Richardson which should be acknowledged. Many water bodies downstream from wetlands depend on nutrient removal for maintaining a balanced ecosystem. Excessive nutrient discharges can overload a wetland's natural capacity to filter nutrients; thus, it can increase the rate of eutrophication and degrade water quality downstream. Wetlands should not be thought of as final sinks for all nutrients discharged to them. Rather, they transform, remove, store and release various forms. In view of the evidence being compiled for several different wetland systems, phosphorus removal at the treatment plant or via land application may be necessary under some circumstances prior to a wetland's discharge, particularly when downstream water quality is nutrient-sensitive.

Heavy Metals. Heavy metals are of concern because of their potential adverse impacts on ecosystems. Opinions differ as to the definition of heavy metals from a toxicological standpoint. The most common heavy metals include arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), silver (Ag), tin (Sn), titanium (Ti), vanadium (V) and zinc (Zn). The aquatic-related fate of these metals has been included in a review of this subject by Callahan et al. (1979). The health impacts, allowable limits related to acute, subacute and chronic toxicity, synergistic or antagonistic actions, teratogenicity, mutagenicity and carcinogenicity have been summarized by Sittig (1980).

Heavy metals entering wetland ecosystems may experience three immediate pathways of transport and translocation: (1) plant or animal uptake, (2) movement to surface or groundwaters and (3) immobilization into the soil matrix. Boyt et al. (1977) reported low concentrations of zinc, copper and lead in the effluent of the Wildwood, Florida, sewage treatment plant and in the receiving swamp. The concentrations of metals in the surface water and sediment cores in a marsh receiving effluent since 1919 (Murdoch and Capobianco 1979) were low and variable, and no trends were detected. Carriker and Brezonik (1976) reported elevated levels of metal associated with surficial sediments of cypress domes receiving secondary effluent.

Aquatic plants undoubtedly assimilate heavy metals from the water (Kadlec and Kadlec 1979, Dinges 1978). The leaves of hyacinth culture receiving treated sewage were found to contain high levels of Cr, Cu, Fe, Hg, Mn, Ni and Zn. However, silver, cadmium and lead concentrations were below detection limits (Dinges 1978). Roots are also known to assimilate metals (Lee et al. 1976). Metals also are complexed by organic compounds such as fulvic and humic acids found in wetlands (Boto and Patrick 1978) and may reduce bioavailability and uptake by insects, plants and animals.

Changes in pH and Eh influence the solubility of metals and determine whether metals are retained or released by the sediments. For example, the release of Al, Mn, Fe, Zn from the sediments was observed when the range was lowered to pH 5-6, but Cs (cesium), Hg and Se (selenium) showed reduced solubility (Schindler 1980). Metals loosely adsorbed to the surficial sediments have not been shown to migrate to groundwaters, but may be mobilized to surface waters (Tuschall et al. 1981). Boto and Patrick (1978) suggested that wetland systems can act as a high capacity sink for heavy metals deposited in the sediments. They warn that natural or man-made alterations of the system (lowering the water table, dredging, etc.) can result in the release of metals trapped in anaerobic sediments. Best et al. (1982) indicate that heavy metal transport in an ecosystem depends on the species of metal, thereby adding another degree of uncertainty to their fate.

The rate of metal accretion and the degree of burial in the sediments are critical factors in determining the loadings which can be endured by wetlands without damage. While the natural attributes of some wetlands provide a sink for some metals, such storage is variable and depends on many factors. As with phosphorus, some wetlands have limited capacity for storing metals. Discharging high levels of bioavailable metals to an ecosystem in which they can be circulated and accumulated should be avoided.

Public Health. The public health implications of wastewater recycling in wetlands have not been evaluated fully for all natural wetland types in Region IV. Potential adverse impacts include increasing the threat of waterborne disease (via surface or groundwater contamination) and increasing the incidence of insect-, bird-, or mammal-vectored diseases. Several Florida wetland types have been studied in this regard, and much current knowledge is derived from these studies. No study to date has been designed to provide direct epidemiological evidence on this subject.

A substantial reduction (90-99 percent) in bacteria (Fox and Alison 1978, Zoltec et al. 1979) and viruses (Scheuerman 1978) has been observed in wastewater passed through typical marsh and cypress dome soil profiles of peat, sand and clay mix. However, Sheuerman (1978) demonstrated that binding was not permanent, and viruses could be released from the soil profile under certain conditions. Wellings (1978) isolated viruses from a well at the same cypress dome experimental site, demonstrating that although the soil profile retained viruses and bacteria, it was not a fail-safe system.

Those wetlands receiving wastewater that interconnect with other bodies of water (lakes, streams, etc.) could potentially transmit bacteria and viruses. At the Jasper, Florida, experimental site, fecal and total coliforms were exported at variable rates, depending on the detention time of the strand (Brezonik et al. 1981). Generally, the longer the detention time, the greater the sedimentation and die-off of coliform populations. Wells monitored at this site indicated a limited sphere of contamination extending vertically in the limestone surrounding the swamp, but groundwater supplies basically were protected (Brezonik et al. 1981).

Concern has been expressed over the possible amplification of the eastern encephalitis (EE) virus in swamps receiving sewage (Davis 1975). Possible increase in bird and mosquito populations associated with EE was the basis for concern. Subsequent study (Davis 1978) of EE vectors of mosquitos and sentinel birds demonstrated that EE activity was not substantially greater in cypress domes receiving sewage than in natural domes. Although known EE mosquito vectors (Culiseta melanura, Culex nigropalpus) increased, human nuisance mosquitos (Aedes infirmata, Aedes atlantica) declined due to elimination of habitat in this case. Mosquito populations elsewhere may react differently and concern has been expressed over the amplification of nuisance mosquito populations.

Other public health aspects of wastewater discharges to wetlands remain uncharacterized. For example, the persistance of nitrate resulting in contamination of drinking water supplies presents potential toxicity problems, especially for infants (methemoglobinemia). Un-ionized ammonia compounds are directly toxic to fish and other creatures (Ruffier et al. 1981). The effects of adverse weather conditions (storm events, freezing, etc.) on treatment efficiency are unknown, and the long-term capability of soil layers to protect groundwater resources is not fully understood. While data exist to indicate the potential for public health problems arising from wetlands discharges, no incidences of disease resulting directly from such discharges have been identified.

8.2.3 Ecology

The important biological components of wetlands include vegetation (terrestrial and aquatic), benthic macroinvertebrates, fish and wildlife.

Vegetation. The magnitude and severity of the effects of wastewater on wetland plant communities depends on the quality of the effluent, the amount of wastewater applied, changes in depth or hydroperiod, the manner in which wastewater is applied and the ability of the wetland ecosystem to assimilate wastewater.

The best documentation of impacts of wastewater on wetland vegetation is derived from the Florida wetland studies (Odum et al. 1984). Impacts were noted in the structure, productivity and biomass components of wetland vegetation. Differences in structural characteristics between cypress domes receiving sewage effluent and control domes were most easily detected in those compartments with short turnover times. For example, leaf biomass in the sewage dome was 1.4 times higher than in control domes. The total leaf area index was more than twice that in the control area due to a dense cover of Lemna (duckweed).

Comparisons of biomass, structure and productivity of domes receiving effluent and other natural systems were made by Brown (1981). She found the chlorophyll a values for the sewage dome were similar to the values reported for floodplain forests, tropical rain forests (2.3 g/m2, Odom 1920) and a cove forest in the Smokey Mountains (2.2 g/m2, Whittaker and Woodell 1969). The high overall chlorophyll a in natural systems resulted from a combination of high leaf area index (LAI) and average leaf chlorophyll a content. Conversely, the sewage dome achieved its high overall chlorophyll a value as a result of an average LAI and high leaf chlorophyll a content.

A marsh near Clermont, Florida, showed increased peak biomass in plants receiving wastewater over those that did not. The presence of standing water resulted in significant physical and chemical changes that affected plant growth. Extensive growth of algae and floating plants was noted. Some species, especially shorter grasses (Panicum spp.), declined in density from increased competition, thus altering community structure. The unavailability of soil oxygen may have limited some plants. Emergent plants such as Sagittaria spp. are not limited by this factor, since they are capable of supplying atmospheric oxygen to their roots through their porous stems, rhizomes and roots. Micronutrients, phosphorus availability and the generation of hydrogen sulfide (toxic to root metabolism) were other factors considered as important deterrents or stimulants to plant growth in this study. These factors are applicable in evaluating impacts to vegetation in other wetlands.

Wastewater was reported to increase the Typha (cattails) and Lemna (duckweed) biomass approximately 30 percent at the effluent outfall in a Michigan marsh, and changed succession patterns (Kadlec et al. 1980). Algae was abundant, but effects declined away from the outfall. Some species shifts were noted as Polygonum spp., Utricularia spp. and Myriophyllum spp. densities declined, possibly outcompeted by Typha and Lemna. No effects on woody vegetation were detected in the short-term study.

Significant impacts on wetland vegetation receiving sewage effluents have been demonstrated in several instances. In a pilot project with sawgrass marshes having limited nutrient uptake ability (Stewart and Ornes 1975), the addition of wastewater severely upset the natural equilibrium of this marsh vegetation. Tree ring analysis showed depressed growth rates of cypress trees during the addition of raw and primary sewage to a hardwood swamp near Jasper, Florida, over a period of 20 years. Data from other systems receiving wastewater, however, indicate increased growth rates.

An Andrews, South Carolina, gum-tupelo swamp receiving wastewater effluent has been reported to be severely damaged (Jones 1982). It has not been determined whether the sewage effluent directly affected the swamp. Indirect hydroperiod stress and catastrophic chemical discharge also have been suggested as causes.

A hardwood swamp receiving effluent continguous with Pottsburg Creek near Jacksonville, Florida, was reported to have a high number of tree crown kills. Winchester (1981) found that the distribution of tree kills in the swamp was unrelated to effluent discharge points in the swamps. It was suggested that hydroperiod alteration, rather than effluent characteristics, was the cause of vegetation impacts.

From these two situations the importance of wastewater characteristics and hydrologic modifications are corroborated. Most stress observed in wetlands systems has related to hydrologic modifications, the introduction of industrial wastewater components or increased sediment from stormwater runoff from uncontrolled development sites.

On a long-term basis, subtle effects have been difficult to detect in the sites studied, but several have been suggested on a generic level. Long-term matinenance of a vegetation community requires replacement of mature organisms. Concern has been expressed that a prolonged hydroperiod may prevent seed germination for cypress and perhaps other woody species. Changes in water chemistry may influence successional trends. Monk (1966) suggested changes from low calcium, pH and water levels to high calcium, pH and water levels (similar to wastewater addition effects) will encourage shifts from ergreen to deciduous vegetation dominants in Florida wetlands. The presence of wastewater also affects the rate of litter fall decomposition in wetlands (Deghi 1976), and the long-term effects on peak composition and accumulation are speculative. Other potential long-term impacts on vegetation include the effects of wastewater on the frequenty and severity of fire in wetlands. Some wetlands are dependent on fire for maintaining their vegetation composition (Monk 1969, Richardson 1980, Ewel and Mitch 1980).

Since vegetation is such an essential component of wetlands, impacts from wastewater additions should be minimized by carefully managing the quality and quantity of effluent introduced to wetlands.

Wildlife. A complicated array of interrelated biological and chemical changes in natural wetlands receiving wastewater may force change on the existing wildlife community. These changes are difficult to quantify, but usually result from changes in the flow rate and water level, and the structure and composition of vegetation. In general, major wildlife impacts can result from changes in:

- Flow rates and water level
- Structure and composition of vegetation
- Amount of edge
- Availability of food.

Changes in flow rates may change the types and densities of escape cover. Water level changes may force changes in the distribution and composition of plant species. Thus, changes in flow rates and water levels determine, in part, changes in structure and composition of vegetation and availability of food.

Changes in water quality after subsequent discharge of treated effluent may cause indirect changes in the wildlife community. Increases in nutrient levels can alter macroinvertebrate, algal and insect populations. Changes in pH and alkalinity may impact fish populations and plant species composition, distribution and biomass. Increased sedimentation may eliminate submerged plants, and reduction in levels of dissolved oxygen may depress normal levels of algal and invertebrate populations. The above impacts could eventually lead to changes in species richness and species diversity through alterations in the quality and quantity of available food.

Wildlife impacts can also be controlled by the quality of wastewater treatment prior to disposal. Poorly treated effluent may contain excessive heavy metal concentrations and viral or bacterial pathogens. Absorption of these constituents by plants and invertebrates may lead to bioaccumulation and increases in the occurrence of wildlife diseases, respectively.

In the Southeast, few long-term studies have been conducted on wildlife impacts resulting from wetland disposal of treated effluent. Harris (1975) studied the effect of sewage effluent on wildlife species endemic to Florida cypress domes. Most benthic invertebrates, fish and juvenile amphibians were eliminated from a dome receiving effluent rich in organic material. Insects concentrated in the center of the dome, which increased the number of frogs present, but anaerobic conditions limited tadpole development. Several migrating bird species increased drastically in numbers during the winter and spring because fly populations increased.

General estimates of the effects of wastewater discharge on wildlife may be inferred from studies outside the Southeast. Kadlec (1979) reported no major shifts in species richness or species diversity at a Michigan lake treatment site after two years of wastewater discharge. Possible long term effects, however, could not be quantified.

8.3 IMPACTS TO WETLAND TYPES

The impacts of wastewater discharges vary significantly from wetland to wetland. As a result, it is not possible to make predictions about the impacts of wastewater on a specific wetland without examining the characteristics of the wetland. Hydraulic and nutrient loading, relative to the specific hydroperiod, vegetation types and flow patterns of a wetland, control the scope and significance of impacts. Some broad generalizations can be made to provide some assistance, based on whether a system is hydrologically isolated or connected. This does not preempt the need to examine wetlands on a site-specific basis. Table 8-3 summarizes the types of impacts that should be evaluated for different wetland types. Known sensitivities to specific alterations are indicated.

Table 8-3. Wastewater Management Considerations for Various Wetland Types.

Systems	Wastewater Management Concerns
Hydrologically Isolated Cypress Domes Carolina Bays, Pocosins, Marshes, Wet meadows, Savannahs, White Cedar Bogs	**General Description** Hydrologic characteristics, soil types and vegetative cover influence capacity to assimilate and adapt to hydraulic and pollutant loadings. Soil structure relationship to retention capacity of wastewater constituents is important. Long term maintenance of dominant vegetation is a concern as well as preservation of ecotype in regions where they are uncommon. As habitats are subjected to development pressures, concern exists for preserving the integrity of these systems, including habitat, recreational and wildlife values, threatened and endangered species and alteration of successional trends.
	Specific Considerations
Cypress Domes	The applicability of established wastewater management techniques established for domes that have been studied should be evaluated. Potentially sensitive to hydrologic modifications.
Carolina Bays, Pocosins	Effects and/or limits of other pollutant loadings (bacterial, metals, toxin) are not well quantified, and effects of increased hydrologic loadings are not well studied.
Marshes, Wet Meadows, Savannahs	Species shifts of macrophytes may be of concern.
White Cedar Bogs	Effects of increasing ambient pH is a concern. Inadequate knowledge of ecosystem structure and function. May be precluded from use due to limited distribution. Ability to retain phosphorus may be limited.
Hydrologically Connected Bottomland Hardwood Forests, Cypress and Mixed Hardwood Strands, Marshes, Freshwater Tidal Wetlands, Bogues, Sloughs, Oxbow Wetlands	**General Description** The critical concern is linkages with downstream water bodies and ecosystems. The abilities of these systems to adapt to increased hydraulic and pollutant loadings is important, although limits of adaptability are uncertain. Retention of wastewater constituents is sometimes difficult to predict. Drainage basin characteristics and orientation of the wetland are critical to nutrient and sediment retention during peak flows. Groundwater interactions can also be important. Preservation of high wildlife and recreational values should be emphasized.
	Specific Considerations
Bottomland Hardwood Forests	Damage to hardwoods may be more difficult to reverse than damages to vegetation with short life cycles. Concern has been expressed about nutrient retention or washout during hydrologic surges. Impact on vegetation growth and species composition.
Cypress and Mixed Hardwood Strands	Management of wastewater flows is critical to wetland maintenance and functional elements of the ecosystem. The applicability of studies in Florida should be evaluated.
Marshes	Short circuiting of wastewater flow through the marsh is a potential concern as well as macrophyte species shifts.
Freshwater Tidal Wetlands	Retention of wastewater constituents, immobilization of toxins, pathogens, metals within wetland site is important. Linkages with adjacent systems are critical, especially for maintaining estuarine water quality and quantity.
Bogues, Sloughs and Oxbow Wetlands	Changing drainage basin characteristics have degraded many of these habitats. Wastewater additions may exacerbate this problem. Loss of wildlife habitat and eutrophication problems must be mitigated. Retention or fate of major wastewater constituents is unstudied.

8.4 UNCERTAINTY AND RISK

Due to the limited information base available concerning wetlands responses to wastewater loadings, the uncertainties and risks of using wetlands for wastewater management should be evaluated. The lack of information is exacerbated by the variability of wetland types and their varying responses to hydrologic or water chemistry changes. This document attempts to portray the state-of-the-art of wetlands use for wastewater management. Nonetheless, significant uncertainties and risks of using wetlands-wastewater systems remain. To the extent possible, these should be understood and incorporated into design and the decision-making framework.

Most guidelines presented by this Handbook recognize uncertainty and risk. Discharge and design guidelines are intended to be conservative based on existing information to account for uncertainties. Suggested construction, operation and maintenance practices are intended to enhance wetland protection and maintenance, thereby reducing risks to the long-term ability of the wetland to assimilate wastewater. This in turn reduces the risks of using wetlands for wastewater management. Uncertainties and risks also are incorporated in the site-selection process. Institutionally, the responsibility of reducing uncertainty and risks lies with the regulatory agencies responsible for implementing wetlands-related standards and issuing wastewater discharge permits.

The degree of uncertainty and risk can be reduced by collecting more information on wetlands receiving wastewater. Specifically, monitoring a proposed or existing wetlands discharge could be expanded to produce sufficient data to reduce the level of uncertainty. From a practical standpoint, a discharger may not have the labor and monetary resources necessary to collect the amount of information suggested. In other situations, however, a modest data collection program might significantly reduce the uncertainties. A tradeoff may be necessary between the level of acceptable uncertainty and risk, and the benefits to be gained through reducing the uncertainty from data collection programs.

Primarily, the uncertainties and risks that should be addressed relate to the following:

1. Assessing the short and long term assimilative capacity of a wetland.
2. Predicting short and long term impacts to the wetland from wastewater loadings.

3. Engineering design criteria enhancing short and long term wastewater assimilation and wetlands protecting.
4. Establishing effluent limits to meet standards or other protective guidelines.
5. Evaluating secondary environmental impacts to the watershed, other wetland uses and wildlife.
6. Determining downstream impacts.
7. Defining the scope of monitoring programs.

The concept of tiering information requests as presented in this Handbook is based on uncertainty and risk. Under conditions where uncertainty and risk are greater (Tier 2) due to lack of knowledge, sensitivity or uniqueness of wetland, or wastewater discharge characteristics, more information may be appropriate for decision making and monitoring.

To the extent possible, each of the considerations presented above should be evaluated in the wetlands feasibility assessment process. If the uncertainties or risks are considered too great for either the adequate protection of wetland uses or the successful long-term operation of the wastewater management system, another site or alternative should be considered.

9.0 ASSESSMENT TECHNIQUES AND DATA SOURCES

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  - o Soils
  - o Geology
- **9.3.3 Hydrology/Meterology Component**
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  - o Flow Patterns
  - o Water Budget
- **9.3.4 Water Quality Component**
  - o Microbiological Parameters
  - o Chemical
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  - o Aquatic Fauna Subcomponents
  - o Terrestrial Fauna Subcomponents

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9.0 ASSESSMENT TECHNIQUES AND DATA SOURCES

Who should read this chapter? Those interested in developing an adequate data base for evaluating a wetlands site or designing a wetlands wastewater system, and those involved with pre- or post-monitoring for a wetlands discharge.

What are some of the issues addressed by this chapter?

- What is involved with designing a wetlands sampling program?
- What methods are most applicable to wetlands parameters?
- How are analyses important to the information base?
- What methods are available to estimate the impacts of wastewater additions on wetland hydraulic and hydrologic variables?
- What are available data sources?

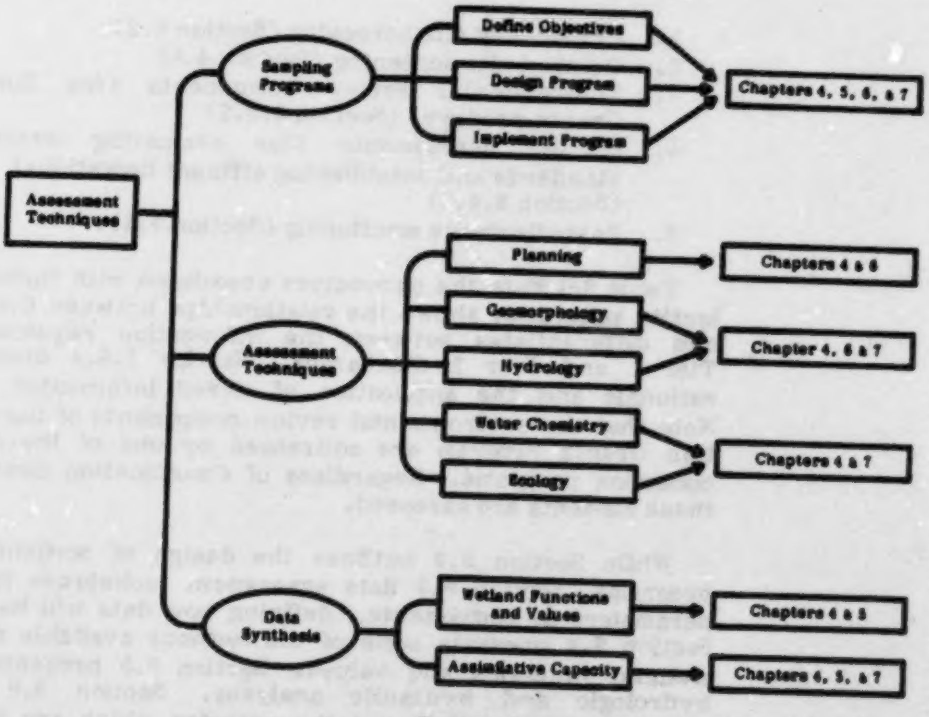

Assessment Techniques
Sampling Programs
Define Objectives
Design Program
Implement Program
Chapters 4, 5, 6, & 7
Planning
Chapters 4 & 6
Assessment Techniques
Geomorphology
Hydrology
Chapter 4, 6 & 7
Water Chemistry
Ecology
Chapters 4 & 7
Data Synthesis
Wetland Functions and Values
Chapters 4 & 5
Assimilative Capacity
Chapters 4, 5, & 7

Figure 9.1 Overview of Chapter 9, Assessment Techniques.

9.1 RELATIONSHIP TO DECISION MAKING

The preceeding chapters of the Handbook have discussed the issues, programs, constraints and incentives associated with the use of freshwater wetlands for wastewater management. They define the decision making framework. This chapter presents methods of data acquisition and evaluation which support the decision making process (Figure 9-1). Further, it provides information for selecting the appropriate assessment technique for a particular situation. In order to select and apply an appropriate technique, a comprehensive data evaluation process is important. Section 9.2 outlines a planning procedure for data acquisition and assessment to support wetland wastewater management decisions. It defines a complete process including 1) definition of objectives, 2) secondary data acquisition, 3) sampling programs, 4) data analysis, 5) interpretation of program results, and 6) the integration of these results into the decision making process. The cost effective acquisition, interpretation and integration of data requires attention to each step in the process.

Five potential data collection and assessment programs have been identified by the Handbook. They are:

1. Preliminary site screening (Section 4.2)
2. Detailed site screening (Section 4.4)
3. Environmental review components (for Construction Grants program) (Section 4.3.2)
4. On-site assessments (for evaluating water quality standards and establishing effluent limitations) (Section 5.4.3)
5. Post-discharge monitoring (Section 7.5).

Table 9-1 lists the parameters associated with these data collection programs, shows the relationships between the programs and differentiates between the information requirements for Tier 1 and Tier 2 discharges. Section 3.3.4 discusses the rationale and the application of tiered information requests. Note that the environmental review components of the Construction Grants Program are addressed by one of the other data collection programs. Regardless of Construction Grant funding these elements are assessed.

While Section 9.2 outlines the design of wetland sampling programs, Section 9.3 lists assessment techniques for specific parameters or components, defining how data will be collected. Section 9.4 presents some of the methods available to evaluate wetland functions and values. Section 9.5 presents potential hydrologic and hydraulic analyses. Section 9.6 identifies available data sources and the agencies which are responsible for collecting and reviewing the data.

Table 9.1 Components of Wetlands Assessment Programs.

Tier		ASSESSMENT PARAMETERS	DATA COLLECTION/ASSESSMENT PROGRAMS*			
			PSS	DSS	OSA	PDM
		Planning				
	1.	Land use				
1	-	Existing land use		X	X	
1	-	Basin land use change (watershed modification)	X		X	X
1	-	Future land use		X	X	
1	-	Wetland ownership/availability	X			
1	-	Accessibility	X			
1	-	Distance to wetland	X			
	2.	Pollutant assessment				
1	-	Wastewater management objectives	X			
1	-	Population estimates	X			
1	-	Wastewater flow projection	X			X
1	-	Wastewater characteristics	X			X
1	-	Other wetland point/nonpoint pollution sources	X		X	X
	3.	Cultural resources				
1	-	Archeological resources		X		
1	-	Historical resources		X		
2	-	Natural resources estimation/use		X		
2	-	Recreation		X		
2	-	Visual/aesthetic		X		
	4.	Institutional				
1	-	Permitting feasibility	X			
1	-	Funding sources		X		
1	-	Existing/future wetlands uses		X	X	
1	-	Potential impairment of existing/future uses			X	X
		Geomorphology				
	1.	Wetland identification				
1	-	Wetland classification (type)	X		X	
1	-	Wetland boundaries/delineation (size, topography)		X	X	
	2.	Relationship to Watershed				
2	-	Watershed morphometry			X	
2	-	Wetland morphometry			X	
	3.	Soils				
2	-	Type		X	X	
2	-	Distribution		X		
2	-	Depth/hardpan		X		
2	-	Other descriptive characteristics		X		
	4.	Geology				
1	-	Sensitive areas (e.g., Karstic, recharge)	X	X	X	
2	-	Surface strata		X		
2	-	Subsurface strata		X		
		Hydrology/Meteorology				
	1.	Water budget				
2	-	Surface water inflows/outflows		X	X	X
2	-	Precipitation		X	X	X
2	-	Evapotranspiration		X	X	X

Table 9.1. Continued.

Tier		ASSESSMENT PARAMETERS	DATA COLLECTION/ASSESSMENT PROGRAMS*			
			PSS	DSS	OSA	PDM
		Hydrology/Meteorology (Continued)				
2	-	Groundwater interactions		X	X	X
2	-	Storage/flood control		X	X	X
2	-	Residence times		X	X	X
	2.	Hydroperiod				
1	-	Sensitivity	X		X	
2	-	Inundation levels (depth)		X	X	X
2	-	Area of inundation		X		X
2	-	Duration		X	X	X
2	-	Flushing ability		X	X	X
2	-	Seasonal wetland relationships		X	X	X
	3.	Flow patterns				
1	-	Hydrologic interconnections	X		X	X
1	-	Flow patterns/channelization		X	X	X
1	-	Recent flow characteristics		X	X	X
2	-	Downstream impacts		X	X	X
		Water Quality				
	1.	Basic analyses				
1	-	Flow		X	X	X
1	-	Dissolved oxygen (DO)		X	X	X
1	-	pH		X	X	X
1	-	Suspended solids		X	X	X
1	-	Biochemical oxygen demand (BOD)		X	X	X
1	-	Water temperature		X	X	X
1	-	Fecal coliforms		X	X	X
1	-	Nitrate		X	X	X
1	-	Ammonia		X	X	X
1	-	Ortho-phosphate		X	X	X
	2.	Elective Analyses				
2	-	Total nitrogen		X	X	X
2	-	Total phosphorus				
2	-	Metals				
2	-	Toxics/Biocides				
2	-	Total coliforms				
2	-	Fecal streptococci				
2	-	Chloride				
2	-	Chlorine residual				
2	-	Conductivity				
2	-	Turbidity				
2	-	Alkalinity				
	3.	W.Q. Assessments				
1	-	Sensitivity	X		X	
2	-	Seasonal influences		X	X	X
2	-	Assimilative capacity		X	X	X
2	-	Nutrient cycling/budget				X
2	-	Acute/chronic toxic potential				X
		Ecology				
	1.	Vegetation				
1	-	Visible stress	X			
2	-	Species composition		X	X	X
2	-	Distribution		X	X	X
2	-	Productivity		X		X
2	-	Other descriptive analyses		X		X
2	-	Percent open water		X	X	X

Table 9.1 Continued.

Tier		ASSESSMENT PARAMETERS	PSS	DSS	OSA	PDM
			DATA COLLECTION/ASSESSMENT PROGRAMS*			
	2.	Aquatic fauna				
2	-	Species composition		X	X	X
2	-	Species diversity		X	X	X
2	-	Other descriptive analyses		X		X
	3.	Terrestrial fauna				
2	-	Species composition		X	X	X
2	-	Frequency of occurrence		X	X	X
2	-	Species diversity		X	X	X
2	-	Other descriptive analyses				X
2	-	Waterfowl breeding and habitat		X	X	
2	-	Wildlife habitat		X	X	
	4.	Integrative assessments				
1	-	Protected species		X	X	
1	-	Sensitivity	X		X	
1	-	Uniqueness	X		X	
2	-	Acute/chronic toxic potential		X	X	X
2	-	Seasonal influences including reproductive cycles		X		X
2	-	Vegetation/habitat evaluations		X	X	

PSS - Preliminary Site Screening
DSS - Detailed Site Screening
OSA - On-site Assessments
PDM - Post-discharge Monitoring

hydrologic and hydraulic analyses. Section 9.6 identifies available data sources and the agencies which are responsible for collecting and reviewing the data.

9.2 DESIGN OF SAMPLING PROGRAMS FOR WETLANDS

Sampling program design is an important aspect of any data collection effort, yet it is often given only cursory attention. The major reason that many sampling programs yield insufficient information is the lack of time and effort given to design. The same can be said for the program that yields an abundance of data but does not provide a basis for management decisions. Many sampling programs have been initiated without addressing fully the major objectives of the program and how the data will be used or interpreted. The design of the program should be based on the decision making processes. The concepts presented in this section are primarily designed for use with wetlands systems. The basic elements of sampling program design have nearly universal application.

Two excellent references on comprehensive environmental sampling programs are Green (1979) and States et al. (1978). These references point out the differences between three types of environmental studies: baseline surveys, monitoring studies, impact assessments. The five data collection programs detailed in previous sections of the Handbook require all three study types. Baseline surveys are intended to define the current state of the wetland system. Monitoring studies are designed to detect long term changes from current conditions as defined by the baseline survey. Impact studies assess the changes caused by a specified impact or activity. Additional references on sampling design include Steel and Torrie (1960), Cochran (1963), Elliott (1977) and Cairns and Dickson (1971).

9.2.1 Define the Decision Making Framework

Sampling programs, data collection and data analysis should provide information required for the decision making process. These processes include feasibility assessments, project siting, engineering design, construction, operation and maintenance and long-term monitoring. The common error of not relating decision making requirements to sampling program design can lead to inappropriate sampling efforts, the waste of project resources and the collection of unuseable data.

Defining the general objectives of a sampling program requires coordination and planning between the applicant and federal, state and local agencies. The Water Quality Sandards and NPDES Program requirements and engineering planning considerations provide the basis for general objectives.

9.2.2 Project Specific Objectives

Initially, the general objectives of a data collection program should be based on decision making requirements. Secondly, project specific objectives should be identified. The following determinations help indicate project specific considerations.

1. Determine how collected data will be used with existing data (if any exists).
2. Determine if data are needed only to fill specific voids in the existing data base.
3. Identify what data are needed to assess the condition of the wetland.
4. Determine if the data will be used to assess the assimilative capacity of the wetland.
5. Evaluate what data are needed to assess the impacts of seasonal influences on wetland functions and values.
6. Decide if the data will be used for computer modeling, as a data base for model calibration and verification.
7. If modeling will be conducted, identify the data requirements of the model that will be used.

Project specific objectives determine the parameters to be measured, the location of sampling sites and the frequency/duration of sampling.

The use of a tiered information requirements system based on discharge size and wetland type might also be incorporated into project specific objectives. The following tasks should help determine how sampling program design will be affected if a tiered information request system has been initiated by your state.

Step 1:
Conduct preliminary site screening (Section 4.2) to assess wetlands site acceptability, define general wastewater management objectives and characterize wastewater.

Step 2:
Define the discharge (e.g., a Tier 1 or Tier 2 discharge) based on the tiering system adopted, if any (see Section 3.3).

Step 3:
Examine the NPDES permit application information requested for your discharge type (Tier 1 or Tier 2).

Step 4:

If the major objectives of the wetlands discharge is disposal/assimilation, and you have a Tier 1 discharge, the information requirements should be established. Go to Step 6.

If you have a Tier 2 discharge or a Tier 1 discharge with wastewater renovation as an objective, additional analyses will probably be required. Proceed to Step 5.

Step 5:

Additional analyses required depend on hydraulic loading and size of discharge. Basic Tier 2 analyses (e.g., as defined in Section 9.3) should be conducted for any Tier 2 discharge. Elective analyses conducted will depend on:

1. Sensitivity of wetland or downstream waters to changes in hydroperiod or water chemistry
2. Other wetlands uses that need to be protected
3. Design for nutrient removal
4. Design for other renovation (e.g., solids removal)
5. Necessity of determining mechanisms for assimilative capacity (e.g., effect of soil type on assimilation of phosphorus)
6. The degree of uncertainty for discharging a particular quantity of wastewater or discharging to a particular type of wetland (e.g., a relatively unstudied wetland type).

Step 6:

The results of Step 4 or Step 5 should help define the information needed for an NPDES permit application. If additional information is needed for engineering planning it should be identified at this point.

Step 7:

Compliance requirements, including post-discharge monitoring, are based on the level of information requested on the permit application and water quality standards applicable to the wetland and downstream waters. Tiering of information requests should parallel that required for the NDPES permit application. Exceptions would be when water quality standards require additional monitoring or effluent limits are not met. In either case, additional information may be requested regardless of whether the discharge is a Tier 1 or Tier 2 discharge. In such cases, data collection and assessment requirements would be site-specific.

A tiered system of information requests could be helpful in providing guidance throughout the decision making and administrative processes. It should be a flexible system that can be tailored to site-specific situations by regulatory personnel. Not only should it be beneficial for regulatory personnel but for the applicant as well by providing a checklist of variables that form the basis of assessing wetlands use for wastewater management.

Tiering is discussed in subsequent sections of this chapter as it pertains to specific elements of sampling program design. Only general guidance can be provided due to the numerous scenarios that would require site-specific adaptations.

9.2.3 Collect and Review Existing Data

The existing data base should be assembled and then evaluated for applicability in meeting the requirements outlined in Tasks 1 and 2 of Figure 9-2. Section 9.6 identifies likely sources for existing (secondary) data. Since much of the existing data base on wetlands has been collected from research studies rather than routine monitoring, its applicability may be limited. Information for the same wetland type may be transferable but this must be done cautiously. The initial field survey is an important element in confirming and understanding the existing data base. Wetland and soils mapping should be field checked to identify boundaries. It is also important to locate other pollutant sources, proximity and type of development, watershed characteristics and access for sampling.

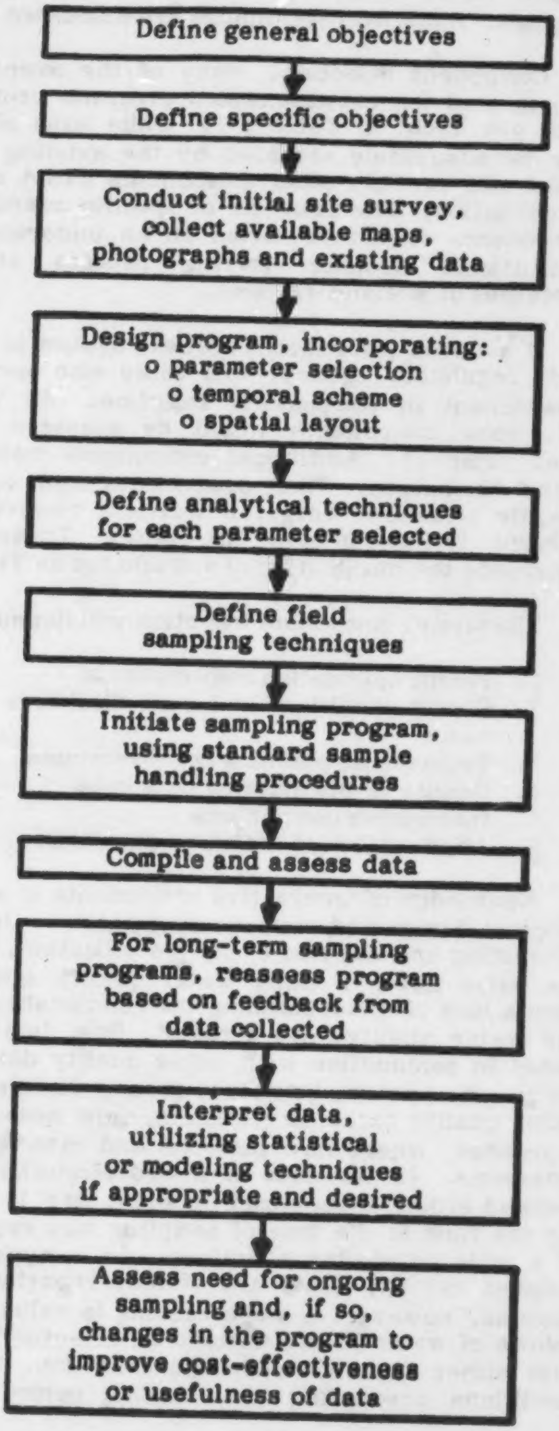
9.2.4 Sampling Program Design

Sampling program design involves not only the determination of what, when, where and how to collect samples, but also the selection of techniques for the analysis of data and the interpretation of results. If the collection and evaluation of secondary or existing data do not meet information requirements, the design of the sampling program should proceed for those components. For impact analyses, objectives should be translated into testable hypotheses. It is beyond the scope of this handbook to provide a comprehensive discussion of experimental design considerations.

Another requirement of sampling program design not discussed in this section is quality assurance and quality control. Most state and federal agencies which would be involved in a wetland wastewater management decision have requirements for written quality assurance/quality control plans. These QA/QC plans specify documented procedures which, when properly implemented, assure the quality of the data. Whether such a plan is required or not, a QA/QC plan should be developed and adhered to throughout the project. USEPA (1978, 1979) provide basic information on QA/QC plans.

The major aspects of sampling program design are discussed below: component selection; scheduling, frequency and duration of sampling; and sampling locations. Sampling techniques

Figure 9.2 Sampling Program Design and Implementation


Define general objectives
Define specific objectives
Conduct initial site survey, collect available maps, photographs and existing data
Design program, incorporating:
o parameter selection
o temporal scheme
o spatial layout
Define analytical techniques for each parameter selected
Define field sampling techniques
Initiate sampling program, using standard sample handling procedures
Compile and assess data
For long-term sampling programs, reassess program based on feedback from data collected
Interpret data, utilizing statistical or modeling techniques if appropriate and desired
Assess need for ongoing sampling and, if so, changes in the program to improve cost-effectiveness or usefulness of data

should follow standard methods and be part of the QA/QC program. Analytical techniques are discussed in Section 9.3

Component Selection. Many of the components that should be analyzed for the assessment programs proposed in the Handbook are listed in Table 9-1. While some of these components may be adequately assessed by the existing data base and the initial site survey, other components listed will require further investigation. The selection of specific components or groups of components should be based on an understanding of both the institutional decision making process and the ecological processes of wetland systems.

If a tiered information request system is established by the state regulatory agency, this could also serve as an important determinant in components selection. As indicated by Table 9-1, some components would be assessed for all discharges (i.e., Tier 1). Additional components may be necessary for Tier 2 discharges. Other components might be examined only for specific situations (e.g., if nutrient removal is anticipated or effluent limitations are not met). These situations would supercede the designation of a discharge as Tier 1 or Tier 2.

Ultimately, component selection will depend on:

1. Permit application requirements
2. Permit conditions and post-discharge monitoring requirements
3. Engineering planning considerations
4. Quality of the existing data base
5. Interactive components
6. Applicability of indicator parameters.

Knowledge of interactive components is essential to sampling program design and components selection. It can also affect the scheduling and location of sample collection. Historically, one of the major flaws of many water quality sampling programs has been a lack of understanding the relationship between hydrology and water quality. As a result, flow data have not been collected in conjunction with water quality data. For a free-flowing aquatic system, this error greatly diminishes the value of the water quality data. In wetlands, flow measurement can present a problem, where flow patterns and rates are often difficult to determine. In the case of a hydrologically open or connected wetland either channelized or sheet flow is occurring. Measuring the flow at the time of sampling may require the installation of a weir or similar structure. In a hydrologically closed or isolated system, flows are of less importance. Even in these systems, however, a stage reading is valuable to determine the volume of water in the wetland and fluctuations that may occur. With either type of hydrologic condition, the hydrometerologic conditions preceeding the sampling period (preferably, for a period of two weeks) should be determined. Another example of interactive components is the relationship of water temperature and dissolved oxygen (DO), since DO saturation is temperature (and salinity) dependent.

Knowledge of indicator components can also be valuable in selecting which components to monitor. Two common indicators that may have value to wetlands monitoring are fecal streptococci and chloride. Fecal streptococci to fecal coliform ratios can sometimes be used to indicate the presence of human contamination. Under some circumstances (e.g., post-discharge monitoring) this could be informative.

Chloride is basically a conservative element, meaning it is relatively inactive in forming bonds that reduce its concentration in solution. As a result, its movement through some surface waters and groundwater can be followed. This could be helpful to a wetlands-wastewater monitoring system to evaluate the movement of effluent containing chloride into the groundwater.

Temporal Considerations. Temporal refers to the timing of sampling: when samples are collected and how conditions present at that time affect the interpretation of the data. **Scheduling** of sampling programs can be affected by several variables, including:

1. Diurnal changes (i.e., changes occurring during the course of a day)
2. Seasonal changes (i.e., changes that occur on a seasonal basis in contrast to a daily basis)
3. Annual variation (i.e., normal variation in conditions between years)
4. Precipitation event (i.e., conditions that result from rainstorms)
5. Drawdown (i.e., conditions that result from dry periods).

Each of these variables can affect water quality and the interpretation of associated data. At a minimum, sampling program design should incorporate these temporal variables and their relationship to wastewater management decisions. The frequency and duration of data collection is also important and is based on program objectives.

As with other elements of sampling program design, the establishment of tiering wetlands discharge information requests could affect data collection scheduling frequency or duration. Tier 2 discharges, due to greater uncertainty, may need to document background conditions and wetland processes in greater detail than a Tier 1 discharge. This could require a study of longer duration or an analysis of more variables. In some fashion, however, Tier 1 dischargers should have a thorough understanding of how the five variables mentioned affect wetland processes, sampling results and engineering design.

Diurnal changes. Daily light and temperature fluctuations are the primary variables controlling diurnal changes. For example, diurnal changes are associated with dissolved oxygen (DO) levels. Assuming a relatively constant water temperature, DO levels are highest when productivity (i.e., photosynthesis) is at its peak and lowest when respiration is at its peak (before dawn). The assessment of DO data must incorporate considerations of diurnal factors. Diurnal patterns are also important when considering wildlife or protected animal species. Species specific animal behavior patterns can influence the probability of sightings and therefore should be incorporated into the sampling design.

Seasonal changes. Seasonal influences affect many water quality and ecological conditions. The following is a listing of several important seasonal variables:

1. Vegetation growth or die-off
2. Microbial activity (water and soils)
3. Nutrient uptake or release
4. Wildlife and water fowl breeding
5. Wildlife and water fowl habitat
6. Temperature and light effects on biochemical and chemical reactions
7. Hydrometeorlogic patterns, affecting flows and nonpoint runoff.

Due to seasonal flow fluctuations and reaction rates, it may be necessary to assess water quality under different seasonal conditions. Seasonal conditions should be noted when samples are collected so data can be properly interpreted and important trends recognized. An assessment of the types of seasonal changes that might be encountered should be undertaken at the time of sampling program design. This can be accomplished by evaluating vegetation types, historical flow or meteorologic patterns, knowledge of potential protected species in the area, and evaluating potential shortcomings of existing data, based on what attributes of a wetland system might have been missed due to the time samples were collected. After the best information available is used in designing the program, modifications can be made during the course of the program if data so indicate. For this reason, it is important to analyze data progressively rather than wait for the completion of the program.

Annual Variation. One of the most difficult factors to incorporate into the sampling design is variation over long periods of time. This can include wetland succession of vegetation (EPA 1983) as well as normal variation in flow and water quality patterns. In wetland systems the question of natural variations versus project impacts is often resolved by consideration of hydrologic factors. For example, a major shift in dominant vegetation of a wetland site receiving wastewater could be attributed in one case to an abnormally dry year and in another case to the discharge. This evaluation would incorporate several factors including the species specific changes in the wetland vegetation. The relatively short period of baseline data at most wetland sites makes this source of variation difficult to estimate. It can be significant, particularly in post discharge monitoring situations, and should be considered in the interpretation of data.

Precipitation Events. A rainfall event can significantly affect water quality; therefore, efforts should be made to assess conditions during and after major storm events. This is essential to understanding the nature of stormwater impacts on the wetland and is important to design considerations (e.g., residence time). As a result of their importance, hydrometeorologic conditions should be recorded when samples are collected. Recent storm events should be noted during routine data collection since stormwater can affect water quality in some systems for several days after a storm event.

For some wetlands, it may be important to evaluate storm events after both a relatively dry period and a wet period. Due to the importance of antecedent soil moisture conditions on runoff, rainfall occurring after a dry period might go primarily into groundwater storage whereas rainfall occurring after a wet period would go primarily into overland flow, causing a major runoff event. These represent only two of the many scenarios that could be possible depending on soil type, soil moisture conditions, period since last rainfall and other variables. Again, the objectives of the sampling program would determine the level of detail given to these considerations.

Drawdown. The term drawdown refers to the periodic condition of many wetlands when water levels drop and, potentially, no standing water occurs. Traditionally, stream water quality has been measured in reference to the 7Q10 flow, which is the seven-day average low flow that can be expected to occur at a frequency of every 10 years. In many wetlands, this has little or no meaning since flows are often sluggish and not channelized. Nevertheless, low flow conditions are important to assess since they reflect the worst-case situation from the standpoint of minimal dilution of effluent. It should be noted, however, that while not typical, some systems receiving wastewater exhibit worse water quality during periods of increased dilution resulting from high flow events. This is due to the nature of the runoff (McKim 1984).

During drawdown periods in wetlands it may be difficult to collect water samples. Low flow conditions should nonetheless be evaluated to assess wastewater impacts to wetlands. This can be critical in wetlands which require drawdown periods to maintain specific vegetation types. Knowledge of the hydroperiod, and water quality conditions associated with different phases of the hydroperiod, may be essential to determining the feasibility of a proposed wetland site and engineering design. Wildlife sightings and habitat can also be affected by dry periods.

The determination of **sampling frequency and duration** is a basic element of any sampling program design. A schedule should be developed indicating for each parameter the total number of times samples will be collected, the time interval between samples and the duration of the sample collection phase. These scheduling components depend primarily upon the attribute of the wetland being studied, sampling program objectives and the specific practical constraints on the study (e.g., funds, personnel).

Several of the components and parameters identified in Table 9-1 can be adequately quantified on a one time basis and are not sensitive to seasonal variation constraints. Examples of nonseasonal, one time factors are the existing land use parameter of the planning component and the subsurface strata parameter of the geomorphology component. Other parameters may require a one time survey but during a specific season: for example, the assessment of wetland vegetation productivity by the annual yield method or the seasonal presence of protected species. Most parameters will require multiple samples collected over a specified period of time. These serial collections are often scheduled at regular intervals. However, this schedule may be inappropriate for many of the significant wetland components. Water quality samples are a prime example of serial collections which are often arbitrarily put on an equal interval schedule (i.e., monthly, weekly). A more appropriate design would include seasonal and short term event factors addressing seasonal flow and temperature patterns, and rainfall events.

The duration of sampling depends on the type of system and level of uncertainty associated with a discharge. For some Tier 1 discharges, for example, two to three months of data may be adequate to define baseline conditions. Where a more sensitive wetland or larger discharge is planned, sampling through a complete seasonal cycle (1 year) may be appropriate. The duration of sampling wetland components after the initiation of a discharge should be defined by permit requirements.

Spatial Design. Location of sampling sites should consider the project objectives, the nature of the system (e.g., hydrologic interconnections, predominant vegetation) and the area of expected project impacts. If information tiering is established, more sampling locations might be necessary for a Tier 2 discharge than for a Tier 1 discharge to characterize the wetland thoroughly. Further, most Tier 1 discharges involve a smaller wetland area so would likely need fewer sampling sites. The parameters required for sampling also affect the number and location of sampling sites due to the different requirements of aquatic and terrestrial, and chemical and biological samplings. Figure 9-3 and 9-4 provide examples of locating sampling sites for different levels of uncertainty or to evaluate different project objectives.

Two of the most important aspects of locating sampling sites are the hydraulic gradient in the wetland and the projected area of impact. Knowledge of the direction of surface and ground water flows is essential to either baseline analyses or impact assessments. Typically, sampling sites are located up gradient and down gradient of a discharge. In wetlands, the determination of hydraulic gradient is often difficult and in some systems changes. Tracer studies may be necessary in some cases to help define the gradient.

Based on the hydraulic loading and prevailing hydraulic gradient, the area of wetland impacted by a discharge can be assessed. The concept of a variable advancing front might be incorporated in sampling program design. This concept reflects that a discharge will not mix completely with wetland surface water but will radiate from the point of discharge, gradually impacting a larger area.

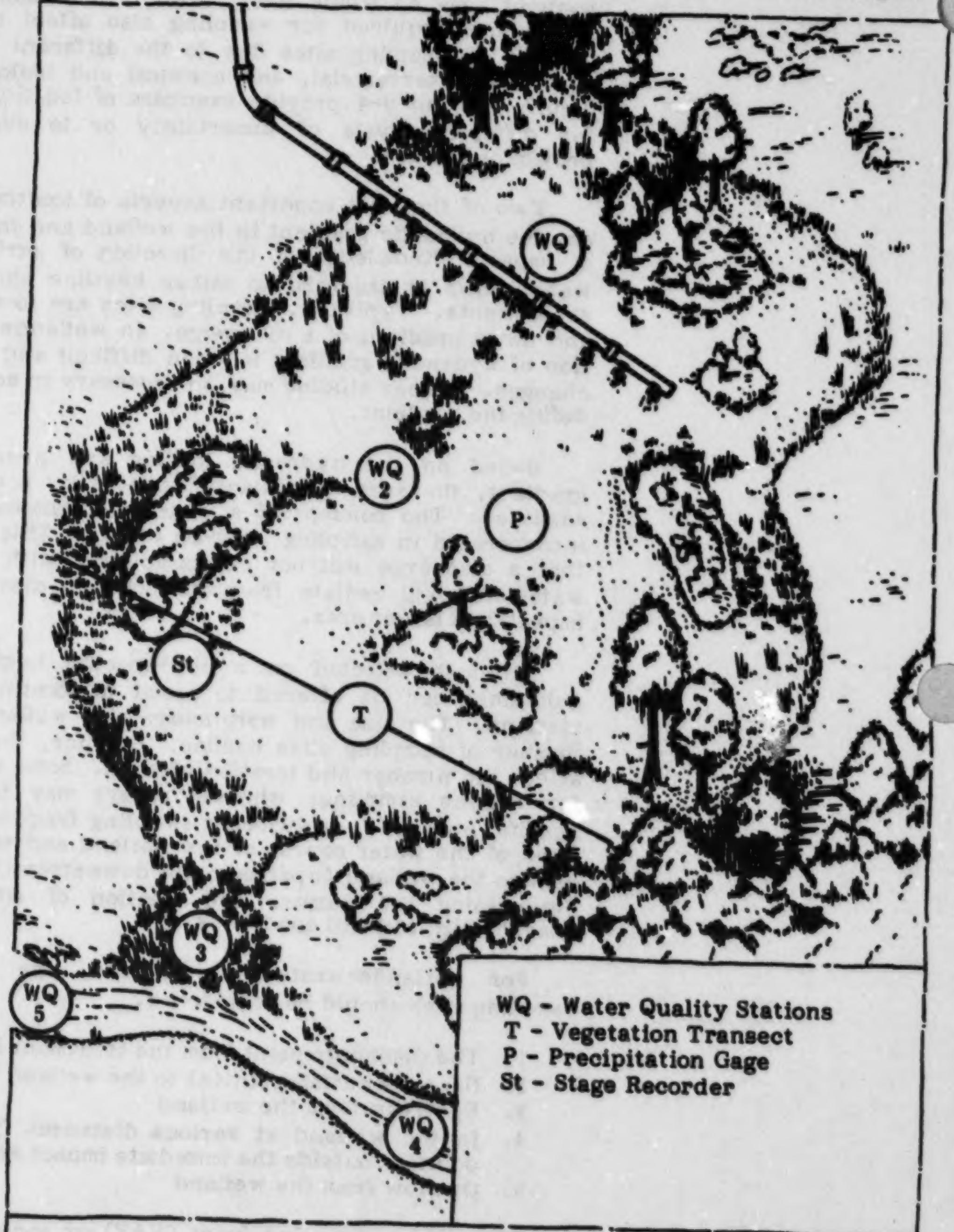
Although selected on a site-specific basis, some general guidelines can be offered to assist in locating data collection stations. The size and morphology of a wetland will affect the number of sampling sites needed. Further, the use of data will affect the number and location of sites. Some sites may be used for routine sampling, whereas others may be used only for specific purposes, at different sampling frequencies. Examining maps of the water course of the wetland and water bodies adjacent to the wetland (upstream and downstream) is also helpful in determining the number and location of sites necessary to characterize wetland conditions.

For wetlands-wastewater systems, the following general sampling sites should be considered.

1. The discharge point from the treatment facility
2. Near the outfall point(s) to the wetland
3. Upstream from the wetland
4. In the wetland at various distances from the discharge point(s) outside the immediate impact area
5. Outflow from the wetland

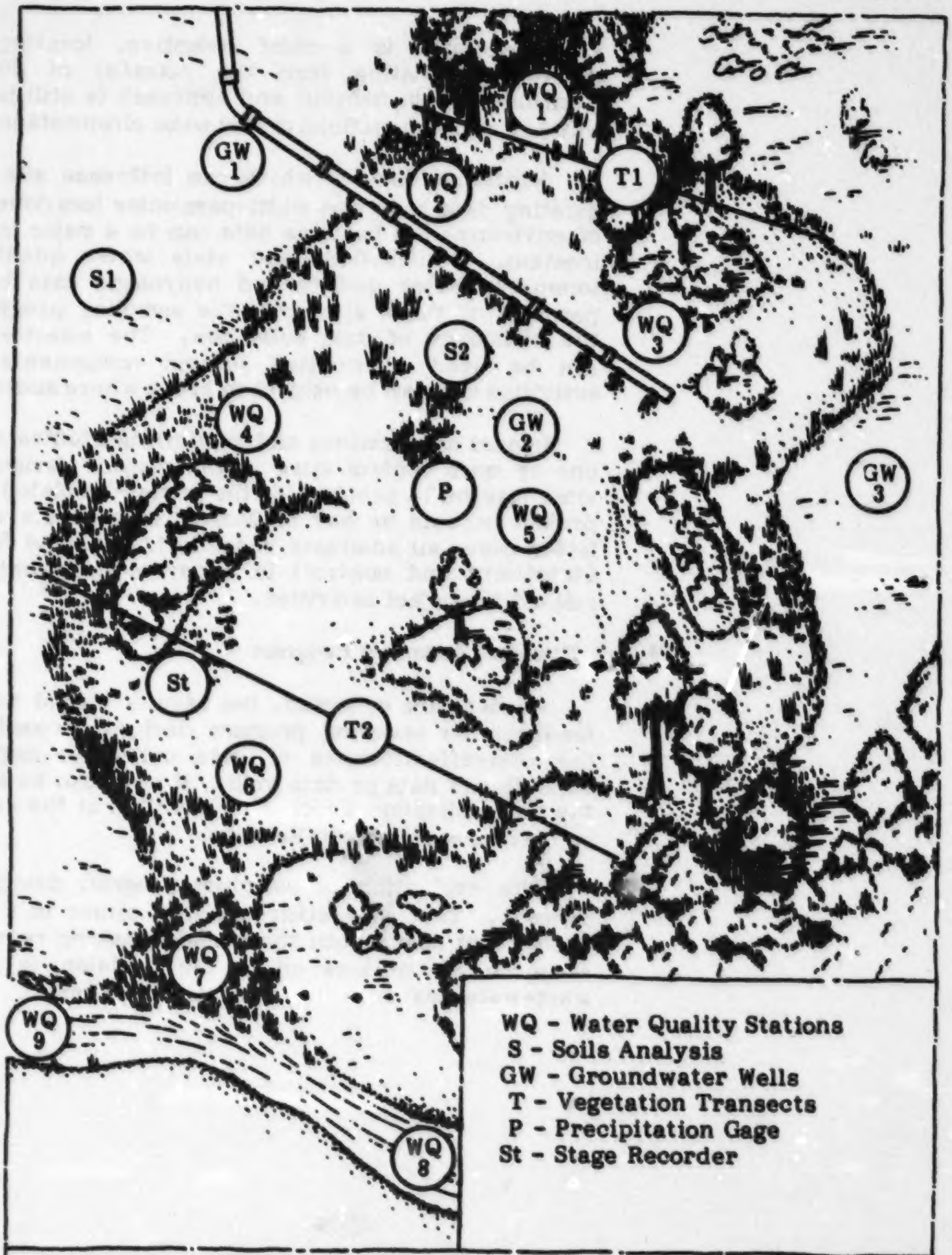
A variable advancing front (VAF) or zone of influence, has been demonstrated by several researchers studying the effects of wastewater on a wetland. To assess the VAF, if assimilation

Figure 9-3. Example of Wetland Sampling Stations for Tier 1 Discharges.


WQ 1
WQ 2
P
St
T
WQ 3
WQ 5
WQ 4
WQ - Water Quality Stations
T - Vegetation Transect
P - Precipitation Gage
St - Stage Recorder

All stations should be sampled before discharge begins.
Source: CTA Environmental, Inc. 1985.

Figure 9-4. Example of Wetland Sampling Stations for Tier 2 Discharges.


WQ 1
GW 1
WQ 2
T1
S1
S2
WQ 3
WQ 4
GW 2
GW 3
P
WQ 5
St
T2
WQ 6
WQ 7
WQ 9
WQ 8
WQ - Water Quality Stations
S - Soils Analysis
GW - Groundwater Wells
T - Vegetation Transects
P - Precipitation Gage
St - Stage Recorder

Transects should be up-gradient and down-gradient from discharge point(s). All stations should be sampled before discharge begins. Source: CTA Environmental, Inc. 1985.

of wastewater is a chief objective, locating sites at fixed distances radiating from the point(s) of discharge may be desirable. This concept and approach is still being investigated but may prove beneficial under some circumstances.

Additional factors which can influence site location are the existing data base and multi-parameter locations. The existence of environmental baseline data can be a major inducement to site location. If U.S.G.S. and state water quality stations have extensive water quality and hydrologic data bases, the incorporation of these sites into the sampling program may increase the efficiency of data collection. The selection of sites which can be used to monitor several components simplifies field activities and can be helpful in areas where access is difficult.

Impact assessments and monitoring studies will often include one or more control sites in the project design. These control sites may be in sections of the wetland isolated from anticipated project impacts or may be located in separate wetlands. In the latter case, an adequate baseline is required for both wetlands (treatment and control) in order to document differences not related to project activities.

9.2.5 Evaluate Sampling Program

As data are collected, the results should be used to provide feedback on sampling program design. Procedures to increase the cost-effectiveness of data collection might be apparent. Superfluous data or data voids, if any, can be identified early in the data collection process rather than at the end of the program so that corrections can be made.

The evaluation of sampling program design is an iterative process. This evaluation can lead either to a realistic program design that meets both the decision making requirements and the resource restrictions or to the decision to not evaluate the wastewater management alternative further.

9.3 DATA COLLECTION TECHNIQUES

The development and evaluation of a wetland-wastewater discharge alternatives involves the collection and analysis of data on a large number of environmental and engineering factors. The purpose of this section is to summarize the more common methods available for environmental data collection. The information base has been organized into five components: planning, geomorphology, hydrology/meterology, water quality and ecology. Each component is described by a list of parameters and associated methods of analysis. The list provides a basis for most wetland investigations, but is not intended to be all inclusive. Methods are referenced to specific literature citations and to the five potential data collection and assessment efforts identified in the handbook: preliminary site screening, detailed site evaluation, environmental review components, effluent limitation assessments and post discharge monitoring. In addition, the tiering concept (Sections 3.3.4 and 9.2) has been incorporated into the descriptions of components as being appropriate for Tier 1 or Tier 2 evaluations. Finally, estimates have been made of the resource requirements for each method. These requirements include cost, personnel, time and equipment.

A narrative description of wetlands parameters is provided in support of the tables summarizing resource requirements. These descriptions indicate the conditions in which a certain parameter might be investigated. The tables list references for the assessment techniques listed. The selection of techniques will depend not only on available resources (e.g., funds, personnel) but also on project objectives. Familiarity with a technique could also enter into the selection process.

9.3.1 Planning Element

The planning component consists of parameters that are generally required for all wetland evaluations (Tier 1). To a large extent the methods are based on standard regional land use and wastewater management planning techniques. As indicated in Table 9-2, four major sections have been identified in the planning component:

1. Land use
2. Pollutant assessment
3. Cultural resources
4. Institutional assessment.

With the exception of some cultural resource parameters, these sections represent basic considerations in the wetland-wastewater alternative evaluation process. Many of the methods

Table 9.2 Comparative Matrix of Methods - Planning.

PARAMETER-METHOD	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS			
			Cost	Personnel	Time	Equipment
1. Land Use						
Existing Basin Land Use						
Existing Maps & Studies		PS,DE,ERC,PDM	Low	Low	Low	Low
Aerial Photo Interpretation		DE	Moderate	Moderate	Moderate	Low
Map Interpretation		DE	Moderate	Moderate	Moderate	Low
Field Survey		DE,PDM	Moderate	Moderate	Moderate	Low
Basin Land Use Change						
Existing Studies		PS,DE,ERC,PDM	Low	Low	Low	Low
Sequential Photo Interpretation		DE	Moderate	Moderate	Moderate	Low
Sequential Map Review		DE	Moderate	Moderate	Moderate	Low
Interview		DE	Low	Low	Low	Low
Sequential Field Survey		DE,PDM	Moderate	Moderate	Moderate	Low
Land Ownership (Availability)						
Tax Register Review		PS,DE,ERC	Low	Low	Low	Low
Interviews		DE	Low	Low	Low	Low
Accessibility						
Distance						
Aerial Photo Interpretation		DE	Low	Low	Low	Low
Map Review		PS,DE,ERC	Low	Low	Low	Low
Site Investigation		DE	Low	Low	Low	Low
Control						
Institutional Review		DE,PDM	Moderate	Moderate	Moderate	Low
Aerial Photo Interpretation		DE	Low	Low	Low	Low
Map Review		PS,DE,ERC	Low	Low	Low	Low
Site Investigation		DE	Moderate	Moderate	Moderate	Low
2. Pollutant Assessment						
Population Estimates						
Census Data		PS,DE,ERC,PDM,OSA	Low	Low	Low	Low
Existing Population Projections		PS,DE,ERC,OSA	Low	Low	Low	Low
Disaggregation Techniques		DE	Moderate	Moderate	Moderate	Low
Photo/Map Interpretation		DE	Moderate	Moderate	Moderate	Low
Field Survey Techniques		DE	High	High	Moderate	Low
New Population Projections		DE	High	High	Moderate	Low
Wastewater Flow Projections						
Literature Reports		PS,DE,ERC,OSA	Low	Low	Low	Low
Local Studies		PS,DE,ERC,OSA	Low	Low	Low	Low
Site Specific Studies		DE	Moderate	Moderate	Moderate	Low
Wastewater Characteristics						
Literature Reports		PS,DE,ERC,OSA	Low	Low	Low	Low
Industrial Classes		DE	Low	Low	Low	Low
Industrial Surveys		DE,PDM,OSA	Moderate	Moderate	High	Low
Land Use Patterns		PS,DE,ERC,PDM,OSA	Moderate	Moderate	Moderate	Low
Direct Sampling (Daily Monitoring Reports)		DE,PDM,OSA	Moderate	Moderate	Moderate	Moderate

Table 9.2 Continued.

PARAMETER-METHOD	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS Cost	Personnel	Time	Equipment
3. Cultural Resources						
Archeological Resources						
National Register of Historic Places		PS,DE,ERC	Low	Moderate	Low	Low
State Historic Preservation Officer		PS,DE,ERC	Low	Moderate	Low	Low
Interviews		DE	Moderate	Moderate	Moderate	Low
Existing Literature		PS,DE,ERC	Moderate	Moderate	Low	Low
Surface Reconnaisance		DE	Moderate	High	Moderate	Low
Site Excavation		DE	High	High	High	Moderate
Laboratory Analysis		DE	High	High	Moderate	Moderate
Mitigation Activity		DE	High	High	Moderate	Moderate
Historical Resources						
National Register of Historic Places		PS,DE,ERC	Low	Moderate	Low	Low
State Historic Preservation Officer		PS,DE,ERC	Low	Moderate	Low	Low
Interviews		DE	Moderate	Moderate	Moderate	Low
Field Survey		DE	Moderate	High	Moderate	Low
Natural Resource Use						
State/Federal Agency Reports		PS,DE,ERC,PDM	Low	Low	Low	Low
Commercial Records		DE,PDM	Low	Low	Moderate	Low
Outfitter Surveys		DE,PDM	Moderate	Moderate	Moderate	Low
Owner's Records		DE	Low	Low	Moderate	Low
Interviews		DE,PDM	Moderate	Moderate	High	Low
Direct Surveys		DE,PDM	Moderate	Moderate	High	Low
Recreation Resources						
Agency Reports		PS,DE,ERC,PDM	Low	Moderate	Low	Low
Commercial Activity		DE,PDM	Moderate	Moderate	Moderate	Low
Use Surveys		DE,PDM	Moderate	Moderate	High	Low
Visual Resources						
Systematic Observation Survey		DE	Moderate	Moderate	Moderate	Low
Photography		DE	Moderate	Moderate	Moderate	Moderate
Viewshed Analysis		DE	Moderate	Moderate	Moderate	Low
Classification Methods		DE	Moderate	Moderate	Moderate	Low
Quantitative Evaluation		DE	Moderate	Moderate	High	Low

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*References: Are primarily secondary data sources - see Section 9.6.

**Applicability: PS - Preliminary Site Survey; DE - Detailed Site Evaluation; ERC - Environmental Review Criteria; OSA - On-site Assessment; PDM - Post Discharge Monitoring.

listed are reviews of secondary data sources and therefore do not include reference citations.

Land Use Parameters

The assessment of land use characteristics in the wetland drainage basin is required for all wetland-wastewater systems. These Tier 1 assessments provide information on current land use patterns and an evaluation of historic and projected land use changes.

Existing Basin Land Use (Tier 1). Information on current land use is often available in the form of studies or maps for a project area. The review of existing studies, maps or aerial photos generally provides sufficient information to assess the compatibility of a wetlands discharge with these land uses. The land use patterns are also the primary data source for nonpoint source pollution evaluations of wetlands. The existing data base can be supplemented through windshield surveys during the preliminary site evaluation work.

Basin Land Use Change (Tier 1). The evaluation of historical and projected land use change is generally based on secondary data sources. If existing studies are available, the assessment of historical changes can be evaluated through the sequential review of maps and aerial photos or through interviews with residents and local officials. The prediction of short-term land use changes is primarily based on the evaluation of land use plans, zoning, plats and building permits. Long-term land use changes are difficult to predict with accuracy and generally rely on the same data sources cited for short-term predictions but utilize disaggregations of population projections. Basin land use changes may affect the ability of wetlands to receive or renovate wastewater through changes in hydrology, runoff patterns and quality, wetland availability, etc.

Land Ownership/Availability (Tier 1). The ownership and potential availability of the wetland and surrounding property needed for easements is generally assessed through the review of tax rolls and interviews of owners or assessors. This assessment is fundamental to projects where wetland ownership is an agency requirement.

Accessibility (Tier 1). As discussed in other sections accessibility refers to two factors: 1) how accessible the wetland is for effluent transportation and 2) how accessible the wetland discharge area is to the public. Effluent conveyance is primarily a function of distance with considerations of land use, topography and geology and may affect construction and operating costs. Public access depends upon wetland location, land use and institutional authority, or control. The evaluation of accessibility is straightforward and required for all alternative evaluations. Public access limitations may be required for public health considerations or for protection from wetland disturbances.

Pollutant Assessments

The assessment of potential pollutant loading is required for all wetland discharges. The assessment procedure utilizes population estimates, land use projections and discharger profiles to estimate the quantity and quality of wastewater generated in the project area for both point and nonpoint sources.

Population Estimates (Tier 1/Tier 2). While estimates of existing and future populations are necessary for projecting wastewater flows, the various sources and methods for these projections can range from simple to complex. Census data for current populations are available by county for all states in the region. Disaggregation to wastewater service areas may not be available for many areas. Most funding agencies require the use of specific, approved population projections (e.g., OBERS). Complications can arise in the disaggregation of these projections to project service areas and in areas where population growth is significantly different from state or regional norms. Discharges from subdivisions or well defined areas can be more easily estimated from plats and occupancy projections. Population estimates based on existing data and simplified methods are acceptable for most Tier 1 applications. Tier 2 discharges may require more advanced methods of estimating population.

Wastewater Flow Projections (Tier 1). The calculation of wastewater flows is generally based on estimates of the service population and assumed wastewater generation rates. Generation rates vary by source (residential, commercial, industrial) and by region. Published estimates of generation rates can be utilized or estimates based on local data can be derived. Sources for local data sources include existing wastewater treatment facilities, public water supplies and industrial monitoring.

Wastewater Characteristics (Tier 1). In order to protect wetland functions an assessment must be made of the wastewater characteristics for all potential wetland discharges. Characteristics can be projected based on the projected number and size of wastewater sources (residential, commercial, industrial) and published generation characteristics. This data should be verified with local information where possible. If industries will be part of the system, a careful review of potential toxics generated by similar industries or a local industrial survey is required. Direct sampling may be needed in cases where effluent quality is unknown or suspected to contain toxics, metals, salts, etc. often associated with industrial wastewater.

Cultural Resources

The evaluation of cultural resources is required for all projects which receive federal funding. Several of the cultural resource parameters are required for all projects (Tier 1), while others may be required only for projects in specific areas. Cultural resources as used here include not only the archeological and historical aspects but also considerations of natural resource use, recreational resources and visual resources. The evaluation of these last three aspects is generally required only in special circumstances relating to specific locations or surrounding land uses (i.e., U.S. Forest Service lands, local parks) or specific water uses (i.e., recreational fishing).

Archeological/Historical Resources (Tier 1). The evaluation of archeological and historical resources is necessary for projects receiving federal (and generally state) funds. This evaluation begins with a review of the National Register of Historic Places and contact with the State Historic Preservation Office and/or State Archeologist for any previously listed sites. The project impact area must then be investigated by a surface reconnaisance field survey. If significant resources are discovered or suspected, additional investigations or excavations are required. Many states have specific requirements for field surveys and reports as well as either approved lists of archeologists or minimum professional requirements. Archeological/historical resources will generally not be a major factor in project viability but may require design modifications for impact mitigation.

Natural Resources Use (Tier 2). Estimates of current and projected natural resource use may be required in areas where the discharge could possibly interfere with recognized and publicly managed natural resources. This Tier 2 requirement is not common to all situations but is conditional upon local conditions. Examples of these circumstances would be the use of wetlands on U.S. Forest Service lands or the impairment of downstream fishing or shellfishing. Additional impacts can occur to the commercial value of forestry, hunting or fishing. Methods for the assessment of natural resource use generally rely on secondary data sources. Direct surveys and interviews would be required in selected Tier 2 situations where there was no existing data, the value of the natural resource was believed to be great and the potential for use impairment was significant.

Recreational Resources (Tier 2). The requirements and conditions discussed for the natural resource use parameter also apply to the recreational resource parameter. However, recreational use of wetlands may be more difficult to quantify than commercial natural resource use. Recreational activities such as fishing or birdwatching may be affected with public accessibility controls.

Visual Resources (Tier 2). The evaluation of visual resources impacts are required only under special circumstances. As noted above the use of pubicly owned land and particularly U.S. Forest Service lands may require special review. In addition, the presence of a historic district or site may require an assessment of visual impacts. The selection of analytical methods is often agency specific and should be selected in conjunction with state and federal officials.

9.3.2 Geomorphology Component

Minimum geomorphological parameters deal primarily with identifying wetland type, and size, shape and topography as well as identifying any sensitive geologic areas. Additional parameters include watershed and wetland morphometry as well as the description of soil and geologic characteristics. Table 9-3 summarizes geomorphology parameters, techniques and resource requirements.

Wetland Identification

The identification of a wetland includes both the delineation of wetland boundaries and the classification of wetland type. Both of these activities are Tier 1 parameters and methods are often dictated by the permitting agency. It is essential for the applicant to review requirements and procedures with the appropriate agency (Section 9.6) prior to the initiation of field work.

Wetland Delineation (Tier 1). The delineation of wetland boundaries is generally based on vegetation, soil and/or hydrologic patterns. An initial estimate of wetland boundaries is often based on U.S.G.S. quadrangle maps with field confirmation. While this approach is generally suitable for preliminary assessments or planning, a more accurate and detailed delineation of wetland boundaries is usually required for project design, permitting and institutional control. The selection of a specific method is largely dependent on site-specific agency requirements and secondary data availability.

Wetland Classification (Tier 1). The initial purpose of wetland classification is to identify sensitive or rare wetland types. This initial classification can be used to identify use restrictions and institutional concerns at an early point in project planning. The permitting agency generally specifies the classification method. In the absence of a specific institutional requirement the National Wetland Inventory system (Cowardin et al. 1979) is recommended.

Relationship to Watershed

The hydrologic behavior of a wetland and the detention of wastewater are largely determined by watershed and wetland

Table 9-3. Comparative Matrix of Methods - Geomorphology.

PARAMETER-METHOD	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS Cost	Personnel	Time	Equipment
1. Wetland Identification						
Wetland Delineation						
Map/Photo Interpretation	15,21,22,23	PS,DE,ERC,OSA	Low	Low	Low	Low
Vegetation Surveys	9,10,14,15,18,19	PS,DE,ERC,PDM,OSA	Moderate	Moderate	Moderate	Low
Soil Surveys	8,15	DE	Moderate	Moderate	Moderate	Low
Hydrologic Surveys	11,13,15,17,20	DE,OSA	Moderate	Moderate	Moderate	Moderate
COE Procedure	4	DE	Moderate	Moderate	Moderate	Low
Florida System	6	DE	Moderate	Moderate	Moderate	Low
Wetland Classification						
Circular #39	5	DE	Moderate	Moderate	Moderate	Low
NWI System	1	DE,PDM	Moderate	Moderate	Moderate	Low
Penfound	2	DE	Moderate	Moderate	Moderate	Low
COE System	4	DE	Moderate	Moderate	Moderate	Low
Godwin & Niering	3	DE	Moderate	Moderate	Moderate	Low
2. Relationship to Watershed						
Watershed Morphology						
Area	11,17	PS,DE,ERC	Low	Low	Low	Low
Slope	11,17	PS,DE,ERC	Low	Low	Moderate	Low
Runoff Characteristics	11	PS,DE,ERC,PDM,OSA	Low	Moderate	Moderate	Low
Time of Travel	11,17	DE	Moderate	Moderate	Moderate	Low
Wetland Morphology						
Area - map methods		PS,DE,ERC	Low	Low	Low	Low
Area - field survey		DE,PDM,OSA	Low	Low	Moderate	Low
Depth - field measurement	11,17	PS,DE,ERC,PDM,OSA	Low	Low	Moderate	Low
Volume - Calculation	11,17	PS,DE,ERC,PDM,OSA	Low	Low	Low	Low
Shape - map		PS,DE,ERC	Low	Low	Low	Low
field survey		DE,PDM,OSA	Low	Low	Moderate	Low
3. Soils						
Type Identification						
7th Approximation Taxonomy	12	DE	Moderate	Moderate	Moderate	Low
SCS maps		PS,DE,ERC	Low	Low	Low	Low
Distribution						
Field Survey	8	DE	Moderate	Moderate	Moderate	Moderate
Aerial Photo Interpretation	8	DE	Moderate	Moderate	Moderate	Low
Mapping	8,15	DE	Moderate	Moderate	Moderate	Moderate
Depth						
Direct Measurement	8,12	DE	Low	Low	Low	Low
Texture						
Feel Method	8,12	DE	Low	Moderate	Low	Low
Sedimentation Analysis	8,12	DE	Moderate	Low	Moderate	Moderate
Direct Seiving	8,12	DE	Moderate	Low	Moderate	Moderate
Organic content						
Oxidation	24	DE,PDM	Moderate	Moderate	Moderate	Moderate
Permeability						
Constant Head Method	24	DE	Moderate	Moderate	Moderate	Low
Falling Head Method	24	DE	Moderate	Moderate	Moderate	Low

Table 9-3 Continued.

PARAMETER-METHOD	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS Cost	Personnel	Time	Equipment
Pan Presence						
Field Survey	24	DE	Low	Low	Low	Low
Chemical/Physical Tests	7,16,24	DE	Moderate	Moderate	Moderate	Moderate
Cation Exchange Capacity						
Ammonium Saturation	24	DE,ERC,PDM	Moderate	Moderate	Moderate	Moderate
Sodium Saturation	7,24	DE,ERC,PDM	Moderate	Moderate	Moderate	Moderate
Nitrogen						
Chemical analysis	7,24	DE?PDM,OSA	Moderate	Moderate	Moderate	Moderate
Phosphorus						
Chemical analysis	7,24	DE,PDM,ELA	Moderate	Moderate	Moderate	Moderate
Metals						
Atomic Absorption Spectophotometry	16,24	DE,ERC,PDM,OSA	Moderate	Moderate	Moderate	Moderate
Flame Emission Spectroscopy	24	DE,ERC,PDM,OSA	Moderate	Moderate	Moderate	Moderate
Inductiviely-Coupled Argon Plasma		DE,ERC,PDM,OSA	Moderate	Moderate	Moderate	High
Wet Chemistry Methods	7,16,24	DE,ERC,PDM,OSA	Moderate	Moderate	Moderate	Moderate
Toxic Pollutants						
Gas Chromotography	7	DE,PDM	High	High	High	High
Gas Chromatograph/Mass Spectroscopy	7,24	DE,PDM	High	High	High	High
Liquid Chromatography	7	DE,PDM	High	High	High	High
4. Geology						
Surface Strata						
Published Reports		PS,DE,ERC	Low	Low	Low	Low
Maps		PS,DE,ERC	Low	Low	Low	Low
Unpublished Local Data		DE	Moderate	Moderate	Moderate	Moderate
Site Specific Testing		DE	High	High	High	High
Subsurface Strata						
Published Reports		PS,DE,ERC	Low	Low	Low	Low
Maps		PS,DE,ERC	Low	Low	Low	Low
Interviews		DE	Moderate	Moderate	Moderate	Low
Site Specific Testing		PC	High	High	High	High
Sensitive Geological Areas						
Published Reports		PS,DE,ERC	Low	Low	Low	Low
Maps		PS,DE,ERC	Low	Low	Low	Low
Interviews		DE	Moderate	Moderate	Moderate	Low

*References: (1) Cowardin et al. 1979, (2) Penfound 1952, (3) Goodwin & Niering 1975, (4) COE 1978, (5) Shaw & Fredline 1956, (6) FAC Section 17-4.02, (7) ASTM 1976, (8) Soil Survey Staff 1951, (9) Brown 1954, (10) Cain & Castro 1959, (11) Chow 1966, (12) Soil Survey Staff 1975, (13) Feverstein & Selleck 1963, (14) Greig-Smith 1964, (15) NESP 1975, (16) Plumb 1981, (17) Soil Conservation Service 1972, (18) Southwood 1966, (19) States et al. 1978, (20) Wilson 1968, (21) Avery 1968, (22) Cowardin & Myers 1974, (23) Kuchler 1967, (24) Black 1965.

**Applicability: PS - Preliminary Site Survey; DE - Detailed Site Evaluation; ERC - Environmental Review Criteria; OSA - On-site Assessment; PDM - Post Discharge Monitoring.

morphology. Under Tier 1 conditions (small discharge/large wetland) these factors are not critical. However, under Tier 2 conditions these factors can greatly influence project performance, particularly if any assimilation is proposed. The cost of these efforts is generally low and, while not required for Tier 1 projects, may prove helpful in project planning and monitoring for all projects.

Watershed Morphology (Tier 2). The nonpoint pollution influences on wetlands are determined by watershed characteristics. The watershed area and land use will determine the characteristics (quality and quantity) of the runoff. The basin slope and channel morphology largely determine the time of travel for the watershed. A major benefit of wetlands is their ability to attenuate stormwater hydrograph peaks and facilitate the removal of nonpoint source pollutants including suspended solids. The interactions between the wastewater discharge and nonpoint source pollution can be important where wetlands are receiving heavy nonpoint source loads or where major modifications are predicted in basin land uses.

Wetland Morphology (Tier 2). While the stormwater inputs to wetlands are controlled by watershed morphology characteristics, the hydrologic response of wetlands are a function of wetland morphology. The area, depth and volume of a wetland give a basic description of morphology. However, the shape of the wetland along with channel morphology can be the overriding factors controlling flow characteristics and in designing flow distribution or discharge structures. With the exception of wetland area, the description of wetland morphology is a Tier 2 activity.

Soils

The consideration of soils in the evaluation of wetland-wastewater alternatives is a Tier 2 analysis. Many parameters should be assessed only under specific circumstances. The selection of analytical parameters is a function of wastewater characteristics, anticipated pollutant retention and impact assessment considerations.

Type Identification (Tier 2). The identification of soil type(s) for a wetland area facilitates the rapid assessment of several chemical-physical properties of the soil. Soil type is the most commonly available information on soils and is mapped for most areas by the Soil Conservation Service. Mineral and organic soils should be identified since they have different characteristics affecting assimilative capacity.

Distribution (Tier 2). The use of SCS maps is the most widely used method for evaluating soil distribution. Additional information may be available from photographic interpretation, but detailed site information or soil distribution is generally obtained through field surveys. SCS mapping units are at too large a scale to provide detailed, site specific information on soil distribution.

Depth (Tier 2). The depth of the soil may be an important factor in wastewater treatment and must be directly measured during the site survey. The depth to different soils, substrate or hardpans can influence site feasibility and design.

Pan Presence (Tier 2). The presence or absence of an impermeable pan layer can significantly influence the water/groundwater interaction of a wetland. A hardpan can contain the groundwater in a surficial aquifer and lead to primarily lateral rather than vertical water movement.

Constituent Removal (Tier 2). The ability of soils to remove constituents from water passing through the soil profile varies. Mineral and organic soils, for example, differ in their ability to take up phosphorus. Often, the cation exchange capacity is used as an indicator of a soils renovative ability. Richardson (1985) has suggested the amount of extractable aluminum in soils may be the best indicator of phosphorus removal. This should be assessed if the renovation capabilities of wetlands are incorporated into design. Texture and permeability can affect the speed with which water moves through the soil profile, thereby influencing the removal and interaction of constituents. In conjunction with information concerning the presence of a hardpan and geologic substrate, texture and permeability help characterize groundwater interactions.

Geology

The major geologic concern of wetland-wastewater discharges is the potential for groundwater contamination. Isolated wetlands in Karstic areas sometimes recharge groundwater, so they need to be evaluated more thoroughly. The assessment of **sensitive geological areas** is a Tier 1 activity based on secondary data sources. The investigation of **surface** and **subsurface strata** could be required at some sites and could involve primary data collection. Geologic information is generally collected when drinking water or monitoring wells are drilled. Since some wetland discharges will require some form of groundwater monitoring, site specific geologic information will be available and can be compared with the existing data base for confirmation of reported geologic structure.

9.3.3 Hydrology/Meterology Component

Hydrology is a natural integrator of most wetland ecosystem processes. Basic hydrologic information which is required for all wetland-wastewater projects (Tier 1) includes data on hydroperiod and flow patterns. Many Tier 2 projects may require the development of a water budget. The detail of this water budget will vary with the complexity and size of the proposed project as well as the sensitivity of the wetland. Table 9-4 summarizes the major components, available assessment techniques and associated resource requirements.

Hydroperiod

Each wetland is unique in terms of location, morphology and other physical parameters that influence the receipt and deposition of water. The frequency, duration and level of inundation are controlled not only by the physical characteristics of the wetland but by the regional climate conditions. In addition, the relationship between the wetland vegetation and hydroperiod is interactive. The assessment of wetland hydroperiod is a Tier 1 analysis and is essential for the proper design and operation of a wetland discharge.

Inundation Levels (Tier 1). The historical and projected level of inundation in a wetland is an important consideration in wetland-wastewater system design as water depth and residence time are affected. The placement, sizing and construction of disposal system components must be appropriate for disposal during both high and low water conditions. Published records of inundation levels are the most reliable source of historical data. The topography of the site provides an upper limit of inundation levels. However, physical indicators (i.e., debris, water stains, erosion, sediment deposits) can provide a short term record of inundation levels and vegetation patterns can provide a long term record of inundation of moderate duration.

Duration and Frequency (Tier 1). The duration of inundation is the dominant factor influencing wetland vegetation distribution. Wetland vegetation in turn affects flooding by retarding surface water flows and controlling water inputs through canopy interception and evapotranspiration. In addition to vegetation patterns, published records and local interviews can be used to quantify duration. Factors influencing the duration and frequency of inundation also include basin size, antecedent moisture conditions and seasonal climatic fluctuations.

Wetland Sensitivity to Inundation (Tier 1). Some wetland systems are sensitive to modifications in hydrologic patterns including both inundation and drydowns (see Table 8-3). Sensitivity to increased inundation is generally related to the degree of hydrologic interconnection with either surface or groundwater. For example, perched bogs may be particularly sensitive to increased inundation. However, some wetland types require periodic drydowns in order to maintain vegetation reproduction (i.e., cypress domes).

Table 9-4. Comparative Matrix of Methods - Hydrology/Meterology.

PARAMETER-METHOD	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS Cost	 Personnel	 Time	 Equipment
1. Hydroperiod						
Inundation Levels						
Published Records	2,5	PS,DE	Moderate	Low	Moderate	Low
Vegetation Patterns	9,10,11,12,13	PS,DE	Moderate	Moderate	Moderate	Low
Physical Indicators		PS,DE	Low	Low	Low	Low
Interviews		PS,DE	Moderate	Low	Moderate	Low
Duration						
Published Record	2,5	PS,DE	Moderate	Moderate	MOderate	Low
Interviews		DE	Moderate	Low	Moderate	Low
Sensitivity						
Vegetation Analysis	9	PD,DE,ERC	Moderate	Moderate	Moderate	Low
2. Water Budget						
Surface Water Flows						
Flow Meters	2,5	DS,DE,PDM,ELA,ERC	Moderate	Low	Moderate	Moderate
Weirs	2,5	DE,PDM,OSA	High	Moderate	Moderate	Moderate
Stage Readings	2,5	PS,DE,PDM	Low	Low	Low	Low
Dye Tracing	4,16					
Precipitation						
Manual Rain Gages	5	DE,PDM	Moderate	Moderate	High	Moderate
Recording Rain Gages	5	DE,PDM	High	Moderate	Moderate	High
Theissen Method	5	DE	Low	Moderate	Moderate	Low
Isohyetal Method	5	PS	Low	Moderate	Low	Low
Existing Data	5	PS,DE	Low	Moderate	Moderate	Low
Evapotranspiration						
Lysimeters	2,5	DE	Moderate	Moderate	Moderate	High
Groundwater Level Fluctuations	2,5	DE	Low	Moderate	Moderate	Moderate
Meteorologic Data Interpretation	2,5	PS	Low	Moderate	Low	Low
Energy Budget	2,5	PS,DE	Low	Low	Low	Low
Groundwater Interactions						
Monitoring Wells	3,7,8	DE,PDM	High	High	Moderate	High
Meteorologic Data Interpretation	1,3,7,8	PS	Moderate	Moderate	Moderate	Low

*References: (1) Bachmat et al. 1980, (2) Chow 1966, (3) Davis et al. 1966, (4) Feverstein & Sellevk 1963, (5) Soil Conservation Service 1972, (6) Wilson 1968, (7) McWharter & Sinada 1977, (8) Todd 1960, (9) Cowardin et al. 1979, (10) Brown 1954, (11) Cain & Castro 1959, (12) COE 1978, (13) FAC Section 17-4.02.

**Applicability: PS - Preliminary Site Survey; DE - Detailed Site Evaluation; ERC - Environmental Review Criteria; OSA - On-Site Assessment; PDM - Post Discharge Monitoring.

Seasonal Wetland Relationships (Tier 1). The frequency and duration of inundation is closely associated with seasonal climatic and vegetation factors. These factors are site and wetland type specific and can be important factors in system engineering design and operation as well as discharge schedules.

Flushing Characteristics (Tier 2). The timing of inundation and the energy associated with flood waters affect the input, retention and export of nutrients and solids. Decreased flows and sheetflow are associated with decreased carrying power and fallout of suspended particles. Flood water provides a vehicle for the resuspension and movement of dissolved and suspended solids. As velocity increases, both sediment input and output increase for the wetland. The flow where output exceeds input is site-specific and is controlled by the physical properties of the wetland (shape, depth) and the antecedent conditions. The determination of the flushing characteristics and seasonal vegetation influences must be determined through mass balancing evaluations of the wetland.

Flow Patterns

Two aspects of surface water flow patterns are easily evaluated in the field. The evaluation of hydrologic interconnections and flow patterns or channelization are Tier 1 requirements. The degree of complexity involved in these evaluations can range from quick, qualitative assessments to extensive, quantitative descriptions. It is important to consider the institutional requirements and decision making utility of this information prior to the initiation of field work. For most applications the qualitative assessment approach is adequate. The assessment of downstream impacts can be complex and is generally required only when nutrient removal is being considered.

The hydraulic gradient is an important aspect of flow patterns. Since most wetlands are in areas of little relief (low slopes) the direction of flow can be difficult to ascertain. Sometimes tracer studies are necessary to delineate flow direction. The hydraulic gradient of groundwater is also important in wetlands with groundwater interactions. Monitoring wells can be used to establish the piezometric surface. For many wetlands this will be the best indicator of flow direction.

Water Budget

Hydrologic budgeting has considerable value as an index to the hydrologic process; it is a means of isolating and estimating individual flow and storage components that influence physical and biological wetland activities. The development of a water budget for a wetland-wastewater project is a Tier 2 activity. It is only conducted when there are serious questions about the influence of wastewater on wetland hydrology or biological systems. A water budget is developed by estimating surface water inflow and outflow, precipitation, evapotranspiration, groundwater inflow and outflow and storage. The U.S.G.S. is currently attempting to develop simplified approaches for estimating water budgets (Brown 1985).

Surface Water Inflows/Outflows (Tier 2). The major flow of water through most southeastern wetlands is by surface waters. While most methods for flow measurement are well established, they are generally appropriate for flow estimation in fixed channels. This requirement presents no problem for wetlands with defined stream channel inflows and outflows. Sheetflow can be difficult to gage and may be a significant source of error in water budgets.

Precipitation (Tier 2). The volume of precipitation in most southeastern wetlands is a function of canopy development, storm composition and prevailing climate. In several wetland types precipitation is the primary input (i.e., perched bogs, pocosins) and measurement accuracy may be critical for the hydrologic budget. In addition to the amount of precipitation, the timing can be an important factor for wetland-wastewater disposal. Seasonal patterns and extreme rain events must be considered in facility design and operation.

Evapotranspiration (Tier 2). Evapotranspiration for a given wetland depends on net radiation, wind speed, total availability of water and vapor pressure gradients. The amount of evapotranspiration varies greatly between wetland and vegetation types. Methods are well established for the estimation of evapotranspiration and estimate accuracy is directly related to the length of the period of record for the data set.

Groundwater Interactions (Tier 2). The importance of groundwater in the water budget depends on the participation of water table aquifers in recharge and discharge processes. Groundwater interactions can be difficult and costly to investigate. The contribution of groundwater inflows and outflows is often calculated by simply balancing the water budget with a net groundwater flow estimate. This net groundwater estimate may indicate either a net discharge or recharge from the groundwater.

Storage (Tier 2). Storage in most wetland situations refers to surface water storage and flood attenuation. Surface storage increases or decreases in response to precipitation, infiltration, evapotranspiration groundwater interactions and surface water inflows/outflows. The ability of a wetland to attenuate flood peaks and storm flows is associated with wetlands having significant out-of-channel storage (e.g., floodplain). Storage is important to wastewater system design since it affects depth, residence time and assimilative capacity of wastewater. It may also influence design of storage or back-up systems during certain conditions.

9.3.4 Water Quality Component

The determination of water quality by chemical, physical and biological analyses has been the traditional method of wastewater discharge impact assessment. Analytical procedures are well established and specific components or parameters are typically required by state and federal agencies for project design, permitting and monitoring.

A large number of parameters is available for evaluation. Table 9-1 has grouped the parameters into basic (Tier 1) and elective (Tier 2) analyses. Analyses required depend on project objectives and the existing data base. The presence of an existing data base is often parameter dependent. Data for traditional monitoring parameters such as dissolved oxygen (DO), pH, residue (solids) and biochemical oxygen demand (BOD) are often available for a given area. Existing data on toxic pollutants and metals are generally much more restricted. Probable sources of data include local, state and federal environmental agencies as well as universities, industries and consulting firms. Seasonal and even daily variation for many parameters can be significant. This seasonal factor should be included in the initial study design and the assessment of the existing data base. Parameters and methods are summarized in Table 9-5.

Temperature (Tier 1). While temperature can have a direct toxic effect, the more likely influence in the wetland discharge setting is the change of chemical reaction rates and equilibrium as well as biological processes. Design and operation restrictions required by freezing temperatures are limited in the Southeast. The thermometric method is most commonly used, although temperature meters are designed into many field instruments.

Color (Tier 2). Modifications in color can influence the production of submergent vegetation by changing the quantity and quality of light. However, turbidity is generally a more appropriate measurement of reduced light penetration.

Conductivity (Tier 2). The ability of a solution to carry an electrical current is expressed as conductivity. The value can be used to assess the effect of total ion concentration on chemical equilibria and biological processes. Conductivity can also be used to estimate total filterable residue.

Residue (Solids) (Tier 1). Residue is an estimate of the dissolved and/or suspended matter in water. The parameter is

Table 9-5. Comparative Matrix of Methods - Water Quality.

PARAMETER—METHOD	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS			
			Cost	Personnel	Time	Equipment
Temperature						
Thermometric	1,2,3	PS,DE,ERC,PDM	Low	Low	Low	Low
Electronic meter	1,3,2	ELA	Low	Low	Low	Low
Color						
Colorimetric	1,2,3,	PS,DE,PDM	Low	Low	Low	Low
Spectrophotometric	1,2,3,		Low	Low	Low	Mod
Tristimulus Filter	1,2,3,		Moderate	Low	Low	Moderate
Conductivity						
Conductivity meter	1,2,3,	DE	Low	Low	Low	Moderate
Residue						
Total	1,2,3,		Low	Low	Moderate	Moderate
Filterable	1,2,3,	DE,ERC,PDM	Low	Low	Moderate	Moderate
Nonfilterable	1,2,3,	ELA	Low	Low	Moderate	Moderate
Settleable matter	1,2,3,		Low	Low	Moderate	Moderate
Turbidity						
Jackson	1	DE,PDM				
Nephelometric	1,2,3,		Low	Low	Low	Moderate
Dissolved Oxygen						
Iodometric	1,2,3,	PS,DE,ERC PDM,OSA	Low	Moderate	Low	Low
Membrane Electrode	1,2,3,		Low	Low	Low	Low
pH						
Electrometric	1,2,3,	PS,DE,ERC,PDM OSA	Low	Low	Low	Low
Alkalinity						
Titrimetric	1,2,3,	DE,PDM	Low	Moderate	Low	Low
Colorimetric	1,2,3,	DE,PDM	Moderate	Moderate	Low	Moderate
Nitrogen						
Ammonia						
Automated Colorimetric	1,2,3,	DE,PDM,OSA	Moderate	Moderate	Moderate	Moderate
Manual Colorimetric/ Titrimetric/Potentiometric	1,2,3,	DE,PPM,OSA	Moderate	Moderate	Moderate	Moderate
Ion Selective Electrode	1,2,3,	DE,PDM,OSA	Low	Low	Low	Low
Organic Nitrogen						
Automated Colorimetric	1,2,3,	DE,PDM	Moderate	Moderate	Moderate	Moderate
Manual: Colorimetric/ Titrimetric/Potentiometric	1,2,3,	DE,PDM	Moderate	Moderate	Moderate	Moderate

Table 9-5. Continued.

PARAMETER-METHOD	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS			
			Cost	Personnel	Time	Equipment
Nitrate						
Ultraviolet	2	DE,PDM	Moderate	Moderate	Moderate	Moderate
Electrode	2	PE	Low	Moderate	Low	Moderate
Cadmium Reduction	1,2,3,	DE,PDM	Moderate	Moderate	Moderate	Moderate
Chromotropic Acid	1,2,3,	DE,PDM	Moderate	Moderate	Moderate	Moderate
Devarda's Alloy Reduction	2	DE,PDM	Moderate	Moderate	Moderate	Moderate
Nitrite						
Spectrophotometric	1,2,3,	DE,PDM	Moderate	Moderate	Moderate	Moderate
Phosphorus						
Vanadomolybdic	1,2,3,	DE,DE,PDM	Moderate	Moderate	Moderate	Moderate
Stannous chloride	1,2,3,	DE,PDM	Moderate	Moderate	Moderate	Moderate
Ascorbic Acid	1,2,3,	DE,PDM	Moderate	Moderate	Moderate	Moderate
Chloride						
Titrimetric	1,2,3,	PE,DE,PDM	Moderate	Moderate	Moderate	Moderate
Potentiometric	1,2,3,	PE,DE,PDM	Moderate	Moderate	Moderate	Moderate
Automated - Colorimetric	1,2,3,	PE,DE,PDM	Moderate	Moderate	Moderate	Moderate
Chlorine, Residual						
Iodometric-Titrimetric	1,2,3,	PDM	Moderate	Moderate	Moderate	Moderate
Ampcrometric-Titrimetric	1,2,3,	PDM	moderate	moderate	moderate	moderate
DPD-Titrimetric/ Colorimetric	1,2,3,	PDM	Moderate	Moderate	Moderate	Moderate
Biochemical Oxygen Demand						
Membrane Electride	1,2,3,	PS,DE,ERC,PDM	Moderate	Moderate	Moderate	Moderate
Iodometric	1,2,3,		Moderate	Moderate	Moderate	Moderate
Chemical Oxygen Demand						
Titrimetric	1,2,3,	PDM	Moderate	Moderate	Moderate	Moderate
Colorimetric	1,2,3,	PDM	Moderate	Moderate	Moderate	Moderate
Toxic Pollutants						
Gas Chromatography	1,3,4	ERC,PDM	High	High	High	High
GC/Mass Spectorscopy	1,3,4	ERC,PDM	High	High	High	High
Liquid Chromatography	3,4	ERC,PDM	High	High	High	High

Table 9-5. Continued.

PARAMETER-METHOD	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS			
			Cost	Personnel	Time	Equipment
Metals						
Atomic Absorption Spectroscopy	1,2,3,4	DE,ERC,PDM	Moderate	Moderate	Moderate	Moderate
Wet Chemistry	1,2,3	DE,ERC,PDM	Moderate	Moderate	Moderate	Moderate
Inductively-Coupled Argon Plasma	1,3,4	DE,ERC,PDM	Moderate	High	Moderate	High
Flame Emission Photometric	1,2,3,4	DE,ERC,PDM	Moderate	Moderate	Moderate	High
Microbiological Parameters						
Total Coliform	1,2,5,6	DE,ERC,PDM	Moderate	Moderate	Moderate	Moderate
Fecal Coliform	1,2,5,6	DE,ERC,PDM	Moderate	Moderate	Moderate	Moderate
Fecal Streptococcus	1,2,5,6	DE,ERC,PDM	Moderate	Moderate	Moderate	Moderate
Pathogenic Bacteria	1,5,6	ERC,PDM	High	High	Moderate	High
Pathogenic Protozoa	1,5,6	PDM	High	High	Moderate	High
Pathogenic Viruses	1,6	PDM	High	High	High	High

*(1) APHA 1980, (2) USEPA 1979, (3) ASTM 1983, (4) Federal Register 1979, (5) Bordner et al. 1978, (6) Breed et al. 1957.

**PS - Preliminary Site Survey; DE - Detailed Site Evaluation; ERC - Environmental Review Criteria; OSA - On-Site Assessment; PDM - Post Discharge Monitoring.

useful for estimates of sedimentation rates and impacts to biological communities and habitats. Residue can also influence other water quality parameters by physical processes (i.e., adsorption) and is a common requirement of permit monitoring, water quality criteria and on-site assessments. Several classifications of residue are commonly reported. Total residue is the material left upon evaporation of a sample. Nonfilterable residue is material not retained by a glass fiber filter while filterable residue is retained by the filter. Results may be reported as wet, dry, volatile or fixed weights depending upon the drying conditions. Settleable matter consists of the gross solids in a sample which physically settle out of solution. Settleable matter may be reported as either volume or weight.

Turbidity (Tier 2). The determination of turbidity is primarily important as an indicator of light penetration and associated influences on submergent vegetation.

Dissolved oxygen (Tier 1). Dissolved oxygen (DO) concentration is a controlling factor in the quality of aquatic habitat for fish and is often used as an indicator of water quality. DO is influenced by temperature, organic loading, reaeration and vegetative activity. Low DO concentrations are typical of many southeastern wetlands which often have a wide diurnal variance. This may limit the use of DO as an indicator of wastewater impacts under some conditions. Additionally, DO will have little significance during dry periods.

pH (Tier 1). The hydrogen ion concentration, pH, is used in the measurement of the acidity of solutions. Variances in pH can have gross effects on the toxicity of pollutants and other reaction kinetics. The surface waters of wetlands are generally acidic (pH less than 7.0). The pH significantly impacts the species composition and water chemistry of wetland systems. Low pH can lead to the release of certain metals.

Alkalinity (Tier 2). Alkalinity is the capacity of a water to react with a strong acid to a designated pH and provides an indication of how well a water body can buffer the addition of acidic wastes. Wetlands have a wide variation in buffering capacity. The degree of impact from wastewater discharges depends on the pH of the discharge and buffering capacity of the wetland. High alkalinities can result in high levels of un-ionized ammonia which can be toxic to aquatic organisms.

Nitrogen. Nitrogen is a macronutrient which in its various forms can be an essential nutrient for plants (nitrate), a contributer to infant methemoglobinemia (nitrite) and a relatively toxic compound (ammonia). The nitrogen cycle in wetlands can include several nitrogen sinks with nitrogen being lost as a gas, being adsorbed to soil particles and being incorporated into organic material.

Nitrate and ammonia are considered Tier 1 parameters while total nitrogen and other forms are Tier 2. This reflects the immediate or rapid impacts of the nitrate and ammonia forms.

Phosphorus. Phosphorus is a macronutrient essential for plant growth. Additions of phosphorus to wetlands can cause increased vegetative growth and modifications to community composition. Phosphorus can be reduced in the wetland system by plant uptake and by adsorption to soil and organic material.

Ortho-phosphate is a mobile ion within wetlands which is readily assimilated by vegetation and is considered a Tier 1 parameter. Other forms of phosphorus are Tier 2 parameters. The multiple forms of phosphorus are determined by variations of filtration, digestion and colorimetric methods.

Chloride (Tier 2). Chloride concentrations are used as a conservative substance to estimate dilution of wastewater in water bodies. Three general methods are available and their application is a function of turbidity and number of samples.

Chlorine (Tier 2). Chlorine is the primary method of wastewater disinfection. The monitoring of chlorine in a wetland system would be used primarily to monitor the proper functioning of the treatment facility and assess chlorine availability for forming chlorinated compounds. Chlorine can be toxic to aquatic organisms and can combine with ammonia to form toxic chloramines. A variety of methods are available to differentiate chlorine forms and overcome interferences.

Biochemical Oxygen Demand (Tier 1). The biochemical oxygen demand (BOD) is a standard laboratory procedure used to estimate the amount of oxygen required for the degradation of organic and inorganic matter. The BOD values are standard requirements for treatment plant design, effluent requirements and discharge monitoring. The variations on the method refer to the options for the measurement of the dissolved oxygen concentrations (Membrane Electrode vs. Iodometric).

Chemical Oxygen Demand (Tier 1). The chemical oxygen demand (COD) measures the amount of oxygen required to oxidize the organic matter in a waste sample with a strong chemical oxidant. COD can be empirically related to BOD and is often measured when BOD concentrations are extremely high.

Toxic Pollutants (Tier 2). A large number of toxic pollutants are possible in wastewater treatment plant effluent, but individual parameters can only be predicted on a site-specific basis. The presence and type of industrial sources for the treatment plant will provide the best indication of likely pollutants. Chromatography and/or spectroscopic techniques are required for analysis. These methods are generally both time consuming and expensive. An existing data base for toxic pollutants is generally not available, and any sampling program must be carefully designed due to cost considerations. The choice of methods is largely parameter specific or dictated by agency requirements.

Metals (Tier 2). A large number of metal parameters are of interest in wetland discharge situations including: calcium, potassium, magnesium, zinc, iron, manganese and sodium. The effluent concentrations of these parameters as well as accumulation in the receiving water body, soil and biological system are often monitored in ongoing wetland discharges. Because of the potential chronic, toxic and food-chain effects, the disposal of industrial wastewater to wetlands should be thoroughly evaluated. While the wet chemistry methods are now seldom used the choice between the other three techniques is largely made on equipment availability, number of samples and specific sample characteristics.

Microbiological Parameters

The analysis of the microbiological parameters of wetland systems generally involves detailed analyses by well-established methods. These standard procedures are detailed in several texts (APHA 1980, Bordner et al. 1978, ASTM 1983, Lennette et al. 1974, Breed et al. 1957). The microbiological parameters range from those commonly included in agency surveys and permit requirements to comparatively rare disease-related organisms.

Coliform Bacteria (Tier 1). Total and fecal coliform are the two most commonly sampled parameters of microbiological studies. These tests are generally run as possible indicators of fecal pollution of waters and as an evaluation of the effectiveness of disinfection techniques at treatment plants. Total coliforms can include organisms from a wide range of sources while the fecal coliform selects for coliforms of fecal material of warm-blooded animals. These tests are almost always required for discharge monitoring.

Fecal Streptococcus (Tier 2). Fecal strep is another parameter commonly used as an indicator of fecal contamination. Fecal coliform/fecal streptococcus ratios are sometimes used to provide information on possible sources of pollution (i.e., treatment plant vs. non-point source pollution). This parameter is seldom required for permit monitoring but is often included in baseline data studies.

Pathogenic Bacteria, Protozoa and Viruses (Tier 2). Several bacteria can cause diseases in man including Salmonella. Shigella, Escherichia coli and Vibrio cholerae. In addition some protozoa (i.e., Giardia lamblia) and viruses can cause diseases.

Tests for these organisms are not generally required in permits but have been incorporated in research studies of wetland discharges.

9.3.5 Ecology Component

The evaluation of the ecological characteristics of freshwater wetlands is one of the more complicated processes in the discharge assessment program due to the complexity and dynamic nature of biological systems. It is essential that clear objectives and procedures are established in the planning phase of ecological studies (Section 9.1). The lack of a well-designed study program can often lead to the waste of project time and funds and the collection of unusable data. The seasonal and annual variation in ecological systems often requires multi-year studies to distinguish between "background" levels and "treatment" changes in system components. This time frame is sometimes longer than many projects can allocate. Therefore, assessments must depend on existing data bases in many cases. The availability of an existing data base varies greatly for different wetland types and locations. Probable data sources of existing studies include government agencies and consulting firms, but detailed ecological studies are more likely conducted by universities and research centers.

Nine ecological subcomponents have been identified as being significant in freshwater wetlands: periphyton, macrophytes, aquatic invertebrates, fish, herpetofauna, birds, mammals, habitat and protected species. These nine subcomponents have been grouped into four sets in order to simplify the discussion: vegetation, aquatic fauna, terrestrial fauna, habitat evaluations. The discussion of habitat evaluations is included in Section 9.4. These groups have several common parameters which are frequently measured in baseline and assessment studies. The only Tier 1 parameters are from the macrophyte subcomponent. Tier 2 parameters should be based on regulatory requirements, wastewater management objectives and wetland sensitivity. The relationship of tiering to commonly measured parameters are summarized in Table 9-6. These parameters are described in Table 9-7.

Analytical procedures are generally significantly different for the same parameters between subcomponents. These procedural differences within common parameters are reflected in the organization of this section. The **subcomponents** are first defined and major factors of importance are identified. Subcomponent-specific parameter **methods** are then summarized. Investigations of the ecological component generally requires the involvement of trained wetland biologists.

Table 9-6. Relationship of Parameters and Tiering to Ecology Components

PARAMETERS	Periphyton	Macrophytes	Aquatic Invertebrates	Fish	Amphibians/ Reptiles	Birds	Mammals
Species Composition	2	1	2	2	2	2	2
Indicator Species	2	1	2	2			
Species Diversity	2	2	2	2		2	2
Relative Abundance	2	2	2	2	2	2	2
Density	2	2	2	2	2	2	2
Distribution		1	2	2	2	2	2
Frequency of Occurrence						2	2
Seasonal Occurrence	2	2	2			2	
Biomass	2	2	2	2			
Productivity	2	2	2	2			
Age Ratio/Distribution				2	2	2	2
Sex Ratio				2	2	2	2
Fecundity				2			
Growth Rate				2			
Condition/Health				2			

1 - Tier 1 Parameters

2 - Tier 2 Parameters

Table 9.7. Frequently Measured Parameters for the Ecology Component of Wetlands.

Species Composition. The kinds and numbers of species jointly occupying a specified area.

Indicator Species. A species whose presence or absence may be characteristic of environmental conditions in a particular habitat.

Species Diversity. The number and abundance of species in a biotic community generally expressed as an index. The use of diversity indices is based on the assumption that environmental perturbations change the index and that this change reflects the degree of impact to the system.

Relative Abundance. The number of individuals of a species in a given time and place relative to the number of individuals of the same species in another time or place.

Density. The number of individuals (or biomass) of a defined group occurring in a specified unit of space.

Distribution. The physical separation of species or groups of species into distinct, limited areas with a larger area.

Frequency of Occurrence. The percentage of samples in which a given species occurs.

Seasonal Occurrence. An observed or predicted noncontinuous pattern of species distribution over time.

Biomass. The total weight of living and dead matter in organisms, often expressed per unit volume or area.

Productivity. The rate at which organic matter is produced by biological activity in an area or volume over time.

Age Distribution. The classification of individuals of a population according to age classes, or age-related periods such as prereproductive, reproductive and postreproductive classes.

Age Ratio. The ratio of the numbers of individuals of a given species contained in two age classes (i.e., larvae/adult).

Sex Ratio. The ratio of the number of individuals of one sex to the other sex for a given species in a given area.

Fecundity. The number of ripening eggs per female fish prior to the next spawning period.

Growth Rate. The rate of change of an individual's length or weight.

Condition. In fisheries biology an estimate of the plumpness of a fish, often expressed as a ratio of width over length. Also a general term referring to the overall health of an organism.

Vegetation Subcomponents

Periphyton. The collective term refers to the algae, bacteria, protozoa and other sessile organisms which grow attached to substrate in the water. The periphytic community in wetlands is less important than the macrophytes in terms of total biomass but can have a significant impact on nutrient transformation and cycling. Periphyton assemblages have been used as indicators of water pollution and could be used in a wetland discharge situation to assess both the degree and area of impact.

Macrophyton. This term includes all multicellular plants with specialized tissues. Macrophytes are generally divided into three groups based on the growth form. Floating plants have true leaves and roots but float on the water surface. Submerged plants are rooted to the bottom and generally grow beneath the water. Emergent plants are rooted in shallow water or in soils with high moisture and have either floating leaves or emergent leaves and steams. The term macrophyte includes plant species as different as duckweed and cypress trees. Therefore, while similar components are evaluated for each group, sampling and analysis techniques can vary considerably. Macrophytes are a major determinant in several wetland classificaton and delineation techniques (Section 9.3.2), provide the dominant habitat characteristics of the wetland and interact with the chemical water quality of the wetland.

Parameters and Methods. The extreme diversity in wetland vegetation species composition, size, density and habitat requires a concomitant diversity in methods. Table 9-8 summarizes parameters and methods for the analysis of wetland vegetation. As previously noted, wetland macrophytes can be defined as floating, submerged or emersed. However, most methods have been developed for terrestrial communities and are defined in terrestrial terms. In general, methods developed for the terrestrial ground stratum or herbaceous plants are applicable to floating or submerged wetland vegetation. Methods for the shrub/tree strata and woody plants are generally applicable for emersed macrophytes. Table 9-9 indicates those methods appropriate for the wetland periphyton, herbaceous and woody vegetation.

The basic description of the macrophytes (species composition and distribution) is required for wetland identification and the assessment of wetland sensitivity. Investigations of the periphyton community are generally restricted to research applications.

Aquatic Fauna Subcomponents

Aquatic Invertebrates. The aquatic invertebrate communities of streams and lakes have been used extensively as indica-

Table 9-8 Common Parameters and Methods for the Analysis of Wetland Vegetation. (P = Periphyton, H = Herbaceous, W = Woody).

	PARAMETERS								
METHODS	Species Composition	Species Diversity	Relative Abundance	Density	Distri-bution	Biomass	Produc-tivity	Growth Rate	Indicator Species
Plot Methods	H,W	H,W	H,W	H,W					
Plotless Methods	H,W	H,W	H,W	H,W					
Transect Methods	H,W	H,W	H,W	H,W					
Line Intercept Method	H,W	H,W	H,W	H,W					
Sedgwick-Rafter Counts	P	P	P	P					
Diatom Species Proportional Counts			P						
Map Generation					H,W				
Map Interpretation					H,W				
Aerial Photo Interpretation					H,W				
Wet Weight						H	H		
Dry Weight						H,P	H,P		
Ash-free Weight						P	P		
Carbon Content						H,P	H,P		
Nitrogen Content						P	P		
Chlorphyll Content						H,P	H,P		
Pheophyton Content						P	P		
Caloric Content						H	H		
Carbon-14 Uptake						H	H,P		
Oxygen Method							P		
ATP Estimates						P	P		
Canopy Cover						W	W		
Basal Area						W	W		
Timber Volume						W	W		
Twig Count						W	W		
Harvest Method						H,W	H,W	H	
Litter Fall Methods							W		
Coring								W	
Taxonomic Keys	P,H,W								
Literature Review	P,H,W	P,H,W	P,H,W	P,H,W	P,H,W	P,H,W	P,H,W	P,H,W	P,H,W
Habitat Requirements									P,H,W

Table 9-9 Comparative Matrix of Methods - Ecology/Vegetation

METHODS	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS			
			Cost	Personnel	Time	Equipment
Plot Methods	1,10,12,13,17,29, 31,32,37,45	DE,PDM,	Moderate	Moderate	Moderate	Low
Plotless Methods	1,6,13,17,20,29, 31,32,37	DE,PDM	Moderate	Moderate	Moderate	Low
Transect Methods	9,16,28,37	DE,PDM	Moderate	Moderate	Moderate	Low
Line Intercept Method	6,9,10,17,33	DE,PDM	Moderate	Moderate	Moderate	Low
Sedgwick-Rafter Counts	42,43,45,46,47,48,49	DE,PDM	High	Moderate	High	Moderate
Diatom Species Proportional Counts	42,43,46,47	DE,PDM	High	Moderate	High	Moderate
Map Generation	2,7,8,14,22,23,35	DE,PDM	Moderate	Moderate	Moderate	Moderate
Map Interpretation	2,7,8,14,22,23,35	PS,PDM	Low	Moderate	Low	Low
Aerial Photo Interpretation	2,7,8,14,22,23,35	PS,PDM	Low	Moderate	Low	Low
Wet Weight	42,43,46,47,48,50, 51,52,53	DE,PDM	Low	Low	Low	Moderate
Dry Weight	42,43,46,47,48,50, 51,52,53	DE,PDM	Low	Low	Moderate	Moderate
Ash-free Weight	42,43,46,47,48,50, 51,52,53	DE,PDM	Low	Low	Moderate	Moderate
Carbon Content	42,43,46,47,50,51	DE,PDM	Moderate	Low	Moderate	Moderate
Nitrogen Content	42,43,46,47,50,51	DE,PDM,OSA	Moderate	Low	Moderate	Moderate
Chlorphyll Content	42,43,46,47,50,51	DE,PDM,OSA	Moderate	Low	Moderate	Moderate
Pheophyton Content	42,43,46,47,50,51	DE,PDM,OSA	Moderate	Low	Moderate	Moderate
Caloric Content	42,43,46,47,48,51	DE,PDM	Moderate	Moderate	Moderate	Moderate
Carbon-14 Uptake	49	DE,PDM,OSA	Moderate	Moderate	High	High
Oxygen Method	42,43,46,51,53	DE,PDM,OSA	Moderate	Moderate	Moderate	Moderate
ATP Estimates	42,43,51	DE,PDM,OSA	Moderate	Moderate	Moderate	High
Canopy Cover	9,11,34	DE,PDM	Moderate	Low	Low	Low
Basal Area	9,18,21,28,30	DE,PDM	Moderate	Low	Low	Low
Timber Volume	6,11,20,26,34,41	DE,PDM	Moderate	Moderate	Moderate	Low
Twig Count	9	DE,PDM	Moderate	Low	Moderate	Low
Harvest Method	9,11,12,25,26,34, 36,39	DE,PDM	Moderate	Low	Moderate	Low
Litter Fall Methods	9,11	DE,PDM	Moderate	Low	Moderate	Low
Coring	9	DE,PDM	Moderate	Low	Moderate	Low
Taxonomic Keys		PS,DE,PDM,OSA	Moderate	Moderate	Moderate	Low
Literature Review		PS,DE,PDM,OSA	Moderate	Moderate	Moderate	Low
Habitat Requirements	4,5,7,8,15,23,38	PD,DE,PDM,OSA	Moderate	Moderate	Moderate	Low

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45. Lund and Talling 1957
46. Schwoerbel 1970
47. Vollenweider 1974
48. Welch 1948
49. Wetzel 1975
50. Wood 1975
51. Sladeckova 1962
52. Owens et al. 1967
53. Westlake 1965

**Applicability: PS = Preliminary Site Survey; DE - Detailed Site Evaluation; ERC - Environmental Review Criteria; OSA - Effluent Assessment; PDM - Post Discharge Monitoring.

tors of water pollution. However, their use in wetland systems has been limited. The lower dissolved oxygen levels and velocities of most wetlands preclude the presence of many of the aquatic invertebrate species used as indicator organisms in streams and lakes. Several components of the invertebrate community can be used as assessment tools for discharge impacts.

Fish. The fish community is often considered by the general public to be the most important component of freshwater wetlands. While many smaller wetlands can have a very limited fish community, larger wetlands can have a significant community and represent a major recreational resource (Section 9.3.1). Fish are difficult to sample quantititatively and generally are poor indicators of pollution due to their mobility. However, long-term studies of the community and short-term studies of pollutant concentrations in tissues can provide valuable information.

Parameters and Methods. The application of specific methods is summarized by parameters in Table 9-10. The wetland aquatic invertebrate community is generally restricted to research applications. The most common invertebrate parameters are species composition, indicator species and diversity. Production and biomass estimates for invertebrates require extensive data collection and analyses. Fish investigations are limited in most studies to species descriptions. Methods for the aquatic fauna subcomponent are well established and documented in the literature. References and estimates of resource requirements are summarized in Table 9-11.

Terrestrial Fauna Subcomponents

Herpetofauna. Reptiles and amphibians are generally not intensively sampled in baseline or monitoring studies with the exception of protected species considerations. Information is generally obtained from literature reports, range maps and habitat evaluations.

Birds. The bird community represents a significant wetland community and is generally included in wildlife surveys. Birds can constitute a signficant recreational resource (hunting/birdwatching) and may involve protected species considerations. Some studies have utilized birds as subjects for bioaccumulation studies or as potential disease vectors.

Mammals. Baseline studies of mammal populations generally require several years of data to establish parameter variability. This level of effort is beyond the scope of most wetland discharge studies with the exceptions of long-term research and post discharge monitoring projects. Impacts to mammals from wetland discharge systems would be nominal under most circumstances. Therefore, most mammal data from these projects

Table 9-10 Common Parameters and Methods for the Analysis of Aquatic Fauna.
(I = Invertebrates; F = Fish)

METHODS	PARAMETERS Species Composition	Species Diversity	Relative Abundance	Density	Biomass	Productivity	Fecundity	Age Distribution	Sex Ratio	Condition	Indicator Species
Qualitative Sampling	I	I	I								I
Quantitative Sampling	I	I	I	I	I	I					I
Net Collection Methods	I,F	I	I,F								I
Artificial Substrate Methods	I	I	I	I	I	I					I
Electrofishing Methods	F		F								
Chemical Collection Methods	F		F								
Indirect Sampling Methods	F										F
Wet Weight					I						
Dry Weight					I						
Ash-free Weight					I						
Average Cohort Method						I					
Hynes-Coleman Method						I					
Direct Measurement							F		F		
Age-Length Frequencies								F			
Scale Analysis								F			
Otolith Analysis								F			
Bioassay										I,F	
Habitat Requirements											I,F
Commercial Data	F					F				F	
Museum Specimen Review	I,F										I,F
Literature Review	I,F	I	I,F	I	I,F	I,F	F	F	F	F	I,F
Taxonomic Keys	I,F										I,F

Table 9-11 Comparative Matrix Methods - Ecology/Aquatic Fauna

METHODS	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS Cost	Personnel	Time	Equipment
Qualitative Sampling	1,2,3,4,5,9,10,11,12,14	PS	Low	Low	Low	Low
Quantitative Sampling	1,2,3,4,5,9,10,11,14	DE,ERL,PDM	Moderate	Moderate	Moderate	Moderate
Net Collection Methods	1,3,4,5,9,10,11,14	DE,ERC,PDM	Moderate	Moderate	Moderate	Moderate
Artificial Substrate Methods	1,4,12,14	DE,PDM	Moderate	Moderate	Moderate	Moderate
Electrofishing Methods	4,9,10,13,14	DE,ERC,PDM	High	Moderate	Moderate	High
Chemical Collection Methods	4,9,10,13,14	DE	Moderate	Moderate	Moderate	Moderate
Indirect Sampling Methods	2,3,4,9,15	PS,DE,PDM	Low	Low	Moderate	Low
Wet Weight	1,2,4,5,9,10,13,14	DE,PDM	Low	Low	Low	Low
Dry Weight	1,4,14,15,16	DE,PDM	Low	Low	Moderate	Moderate
Ash-free Weight	1,5,14,16	DE,PDM	Low	Low	Moderate	Moderate
Average Cohort Method	4,16	DE,PDM	High	Moderate	High	Low
Hynes-Coleman Method	4,16	DE,PDM	High	Moderate	High	Low
Direct Measurement	1,2,3,4,9,10,13,14	DE,PDM	Low	Moderate	Low	Low
Age-Length Frequencies	1,2,4,9,10,14	DE,PDM	Low	Low	Moderate	Low
Scale Analysis	4,9,10,13	DE,PDM	Moderate	Moderate	High	Moderate
Otolith Analysis	4,9,10,13	DE,PDM	Moderate	High	High	Moderate
Bioassay	1,9,10,14	DE,ERC,PDM,OSA	High	High	Moderate	High
Habitat Requirements	2	PS,DE,ERC,PDM	Moderate	Moderate	Moderate	Low
Commercial Data	-	PS,DE,ERC,PDM	Low	Low	Low	Low
Museum Specimen Review	-	DE,PDM	Moderate	Moderate	Moderate	Low
Literature Review		PS,DE,ERC,PDM,OSA	Moderate	Moderate	Moderate	Low
Taxonomic Keys		DE,ERC,PDM	Moderate	Moderate	Moderate	Low
Species Association	5,6,7,8,9,14	PS,DE,ERC,PPM	Moderate	Moderate	Moderate	Moderate

*References:

1. APHA 1980
2. Bennett 1971
3. Edmondson 1959
4. Edmondson and Winberg 1971
5. EPA 1975
6. Gennon and Stemberger 1975
7. Hutchinson 1967
8. Hynes 1970
9. Lagler 1956
10. Ricker (ed.) 1968
11. Schwoerbel 1970
12. Southwood 1966
13. Weatherley 1972
14. Weber 1973
15. Welch 1948
16. Winberg 1971

**Applicability: PS = Preliminary Site Survey; DE - Detailed Site Evaluation; ERC - Environmental Review Criteria; OSA - On-site Assessment; PDM - Post Discharge Monitoring.

would be expected to be based on existing studies, habitat requirements and availability, range maps, reported sightings and minimal direct collection studies. Due to the mobility of most mammals, impacts from wetland discharges would be difficult to demonstrate.

Parameters and Methods. Terrestrial faunal investigations apply only to Tier 2 projects. The basic requirement is for descriptions of species composition and distribution. More detailed descriptions are required on a project specific basis. Selected methods for parameters and method references and resource requirements are summarized in Tables 9-12 and 9-13.

Table 9-12 Common Parameters and Methods for the Analysis of Terrestrial Fauna.
(B = Birds; A = Amphibians/Reptiles; M = Mammals)

	PARAMETERS								
METHODS	Species Composition	Species Diversity	Relative Abundance	Density	Distri-bution	Frequency of Occurence	Seasonal Occurence	Sex Ratio	Age Ratio
Whole Area Counts	B	B	B	B	B	B	B	B	
Time-Area Counts	B,M	B,M	B,M	B,M	B,M	B,M	B	B	
Strip Counts	B,A,M	B,M,	B,A,M	B,M,	B,A,M	B,A,M	B	B	
Roadside Counts	A,M	M	A,M	M	A,M	M			
Auditory Counts	B,A	B	B,A	B	B,A	B	B		
Indicator Counts	B,M	B	B		B,M	M	B		
Night-Light Counts	M	M	M	M	M	M			
Aerial Census	B,M	B,M	B,M	B,M	B,M	B,M	B	B	
Mark-Recapture Method	B,A,M	B,M	B,A,M	B,A,M	B,A,M	B,A,M	B	B,A M	B,A,M
Removal Trapping	M	M	M	M	M	M		M	M
Non-Removal Trapping	B,A,M	B,M	B,A,M	M	B,A,M	B,A,M	B	B,A,M	B,A,M
Scent Stations	M				M	M			
Opportunistic Observations	A		A		A	A			
Range Maps	B,A				B,A				
Community Evaluation	B	B	B	B					
Habitat Evaluation					B,A,M		B		
Museum Specimens	B,M	B,M							
Taxonomic Keys	B,A,M								
Literature Review	B,A,M	B,M	B,A,M	B,M	B,A,M	B,A,M	B	B,A,M	B,A,M
Interviews	B,A,M				B,A,M		B		

Table 9-13 Comparative Matrix of Methods - Ecology/Terrestrial Fauna

METHODS	REFERENCES*	APPLICABILITY**	RESOURCE REQUIREMENTS Cost	Personnel	Time	Equipment
Whole Area Counts	1,6,12,32,37,39,43	DE,PDM	Moderate	Moderate	Moderate	Low
Time-Area Counts	6,23,27,32,37	DE,PDM	Moderate	Moderate	Moderate	Low
Strip Counts	4,6,18,19,24,30,41	DE,PDM	Moderate	Moderate	Moderate	Low
Roadside Counts	1,6,7,12,14,29,32,42	DE,PDM	Moderate	Moderate	Moderate	Low
Auditory Counts	2,5,25,26,37,43	DE,PDM	Moderate	Moderate	Moderate	Low
Indicator Counts	11,12,13,22,32,36	DE,PDM	Moderate	Moderate	Moderate	Low
Night-Light Counts	3,5,37,40,43	DE,PDM	Moderate	Moderate	Moderate	Moderate
Aerial Census	5,10,14,20,31,46	DE,PDM	High	Moderate	Moderate	High
Mark-Recapture Method	23,27,37,43,47	DE,PDM	High	Moderate	High	Moderate
Removal Trapping	27,28,37,43,48	DE,PDM	High	Moderate	High	Moderate
Non-Removal Trapping	15,17,23,37,43	DE,PDM	High	Moderate	High	Moderate
Scent Stations	33,34,48	DE,PDM	High	Moderate	Moderate	Moderate
Opportunistic Observations	27,37,43,44	PS,DE,ERC,PDM	Moderate	Moderate	Low	Low
Range Maps	12,27,37,43,44	PS,DE,ERC,PDM	Low	Low	Low	Low
Community Evaluation	8,16,27,38	DE,PDM	Moderate	Moderate	Moderate	Low
Habitat Evaluation	3,8,9,21,45,46	PS,DE,ERC,PDM	Moderate	Moderate	Moderate	Low
Museum Specimens		DE,PDM	Moderate	Moderate	Moderate	Low
Taxonomic Keys		DE,PDM	Low	Moderate	Low	Low
Literature Reviews		PS,DE,ERC	Low	Low	Moderate	Low
Interviews		PS,DE,ERC,PDM	Low	Low	Low	Low

*References:

1. Albers 1976
2. Alcorn 1971
3. Anderson et al. 1972
4. Anderson et al. 1976
5. Bear 1969
6. Berthold 1976
7. Brewer 1972
8. Brower and Zar 1977
9. Brown 1974
10. Caughley 1974
11. Cochran & Stains 1961
12. Craighead & Craighead 1969
13. Daniel et al. 1971
14. Diem and Lu 1960
15. Dolbeer & Clark 1975
16. Eberhardt 1971
17. Edwards & Eberhardt 1967
18. Emlen 1971
19. Emlen 1977
20. Enderson 1970
21. Evans & Gilbert 1969
22. Ferguson 1955
23. Flyger 1959
24. Franzreb 1976
25. Gates 1966
26. Gates & Smith 1972
27. Golley et al. 1975
28. Hayne 1949
29. Howell 1951
30. Jarvinen & Vaisanen 1975
31. Kadlec & Drury 1968
32. Kendeigh 1944
33. Linhart & Knowlton 1973
34. Linhart & Knowlton 1975
35. Lord 1959
36. Neff 1968
37. Overton 1971
38. Pielou 1975
39 Porter 1974
40. Proguiske & Duerre 1964
41. Robinette et al. 1974
42. Sauder et al. 1971
43. Seber 1973
44. Stebbins 1966
45. Thilenius 1972
46. USFWS & Canadian WS 1977
47. Wilber 1975
48. Wood 1959

**Applicability: PS = Preliminary Site Survey; DE - Detailed Site Evaluation; ERC - Environmental Review Criteria; OSA - Effluent Assessment; PDM - Post Discharge Monitoring.

9.4 ECOLOGICAL ASSESSMENTS

Many aspects of wetland assessments deal with the interactive nature of wetland processes and values. Hydrologic characteristics can be controlled by geology. Likewise, the type of vegetation can be impacted by hydrology, soils and vegetation. Under some circumstances vegetation can affect water chemistry, and under others water chemistry can affect vegetation. The same interaction exists between wildlife and vegetation. These types of interdependencies need to be considered in evaluating a potential wetlands discharge and associated data assessments. Three major types of interactive, or ecological, assessments should be evaluated:

1. Wetlands functions and values
2. Assimilative capacity
3. Habitat associations

9.4.1 Wetlands Functions and Values

Several integrative methods to assess wetlands functions and values have been developed. Five such methods are summarized on Table 9-14.

The Adamus and Stockwell methodology is widely accepted as the most comprehensive technique for assessing wetland functions. This method was prepared for evaluating the effects of highway development on wetlands but has a broader range of applicability. The two volume document describing the method addresses the fundamental aspects of wetland functions and values. While it provides much useful information for wetlands analyses, including those for wastewater management, its application requires a knowledgeable wetland scientist. For wetlands wastewater management applications in particular, the method provides detailed information that would not be required of most potential dischargers. However, the method should be useful to potential dischargers for characterizing wetland functions and values, which is an important aspect of a wetlands wastewater assessment. The other methods listed in Table 9-14 also have potential application for assessing wetlands functions and values. A numerical weighting system is used by some methods to help quantify the techniques for the purpose of comparing wetlands characteristics.

These methods are applicable for evaluating wetlands functions and values for wastewater management assessments. The selection of which technique to use might be based on the amount of information required for decision making. Generally, in order of increasing sophistication and decreasing ease of use, these integrative methods vary as follows:

Table 9-14 Parameters and Methods for the Analysis of the Wetlands Functions and Values Component.

	METHODS				
	FHWA (Adamus & Stockwell)	Michigan Manual for Wetland Evaluation Techniques	Maryland Wetlands Evaluation (McCormick & Somes)	Wetlands Study of Seminole County (Brown & Starnes)	Ontario Wetland Evaluation
Delineation of Natural Drainage/Storage	X	X	-	X	X
Watershed Characteristics	X	X	X	-	-
Uniqueness	-	-	X	-	X
Cultural Resources	X	X	-	-	X
Economic Values	-	X	-	-	X
Cost Assessments	X	-	X	-	-
Size	X	-	X	-	X
Soils	X	X	-	-	X
Wetland Type	X	X	X	-	-
Hydrologic Classification	X	X	-	-	-
Hydroperiod	X	-	-	X	-
Groundwater Recharge	X	-	-	X	-
Groundwater Discharge	X	-	-	X	-
Meteorologic Influences	X	-	-	X	-
Flood Storage	X	X	-	X	-
Shoreline Anchoring	X	-	-	-	
Sediment Trapping	X	X	-	-	-
Water Quality	X	X	-	X	-
Nutrient Retention	X	X	-	-	X
Vegetation Assessments	X	X	X	X	X
Primary Production	-	-	X	X	-
Food Chain	X	-	X	-	X
Fisheries Habitat	X	X	-	-	X
Wildlife Habitat	X	X	X	X	X

1. Michigan
2. Ontario, Brown and Starnes, McCormick and Somes
3. Adamus and Stockwell.

9.4.2 Assimilative Capacity

Determining the assimilative capacity of a wetland generally requires an additional level of analysis than typically required for assessing wetland characteristics. The determination of assimilative capacity is often difficult because the processes controlling assimilation are not fully understood nor identified. Further difficulties are often introduced because the "overall" assimilative capacity of a wetland is evaluated rather than that of specific elements. For example, Richardson (1985) has shown that in some wetlands the fraction of extractable aluminum in the soil may be the best indicator of phosphorus removal potential. For other constituents, water depth or velocity may be the most important determinants. These analyses can, therefore, be complicated due to the interactive nature of wetlands processes.

In evaluating assimilative capacity, identifying the components for which assimilation is desired should be the first step. Second, the processes controlling the assimilation of these components should be evaluated. Third, the driving forces of these processes should be analyzed. The methods described for evaluating wetlands functions and values also provide information on assimilative capacity. For example, Adamus (1983) indicates the type of wetlands that might be expected to provide greater nutrient or sediment removal based on a series of wetland characteristics.

Other means for assessing assimilation are presented by Chan et al (1981) by analyzing the nutrient or metal removal potential of various vegetation types. Although vegetation comprise a smaller nutrient and metal removal compartment than soils for most wetlands, vegetation is important in assimilation.

The following characteristics have been observed to affect the assimilative capacity of a wetland:

1. Meandering channels, with slow-moving water and large surface areas, enhance settleable pollutant removal by sedimentation.
2. Groundwater seepage wetlands or shallow flow regimes are effective for removal of pollutants such as phosphorus and metals by adsorption to the soil.
3. Groundwater seepage wetlands, meadows and thickly vegetated wetlands are particularly useful for filtering colloidal suspensions and where filtration is important.
4. Nitrogen removal by denitrification will occur in anaerobic bottom sediments common to wetlands. Deeper areas, where

sediments and organic detritus can accumulate in an anaerobic environment could be designed into a wetland intended for nitrogen removal.

5. BOD removal in wetlands is accomplished by microorganisms. Optimal BOD removal will be achieved where there is greater surface area (soil, plant stems, leaves and roots) for microbial growth, uniform distribution fo the BOD load, and adequate dissolved oxygen. Open water surfaces in the wetland will increase oxygen transfer to the water. Oxygen in the surface water also keeps orthophosphate precipitated.
6. Because many types of vegetation are selective in their accumulation and biomagnification of various heavy metals, mixed stands of vegetation may provide the best overall heavy metals removal.
7. Varied or mixed wetland systems containing features of ponding for sedimentation, shallow areas for adsorption by soil, and mixed vegetation, have high potential for treating municipal wastewaters.
8. Rapid plant growth, generally associated with harvesting, optimizes nutrient removal. For such applications, a monoculture system, such as a hyacinth pond, can be very effective. However, large amounts of vegetation must be harvested.

9.4.3 Habitat Evaluations

The interactive nature of wetland systems can be utilized in habitat evaluations to summarize the value or predicted impacts to various wetland communities. An assessment of habitat and habitat values with either a quantitative or qualitative method is utilized in almost all wetland evaluations. Habitat is the combination of biotic and abiotic factors at a given site. The value of a habitat must be assessed in relation to a specified purpose or species (i.e., water fowl breeding or white tailed deer). The assessment of terrestrial habitat is often largely based on vegetation, soil moisture, slope and proximity to water. Aquatic habitat is generally assessed in terms of substrate type, flow, water quality and vegetation. The evaluation of wetland habitat involves combinations of all these factors. Habitat evaluations are generally not required in NPDES permits but may be appropriate for wetland discharges. The assessment of wetland habitat is used extensively to evaluate the possibility or likelihood of the presence of wildlife and protected species.

Wetland Habitat Procedures. Table 9-15 summarizes the analytical factors utilized in five different methods for wetland habitat evaluation. These five examples are representative of the many methods which have been utilized for habitat evaluations.

Table 9-15 Factors and Methods for the Analysis of Wetland Habitat

	METHODS				
FACTORS	HEP	HES	Hamor	Whitaker & McCuen	Baskett et al.
Aquatic Habitat	X	X	X		
Terrestrial Habitat	X	X	X	X	X
Professional Judgment Dependent			X		
Quantitative Dependent	X	X		X	X
Field Surveys	X	X	X	X	X
Map Interpretation	X	X	X	X	X
Aerial Photo Interpretation	X	X	X	X	X
Habitat Quality	X	X	X	X	X
Evaluation Species	X		X		X
Computer Modeling				X	
Land Use Patterns	X	X		X	
Hydraulic Structure					
Hydraulic Patterns	X	X	X		
Hydraulic Modification	X	X			
Water Quality	X	X			
Vegetation	X	X	X	X	X
Wildlife Requirements	X		X	X	X
Reproductive Requirements	X			X	

The Hamor (1974) method for evaluating habitats is the most rapid, but least reproducible, and is highly dependent on professional judgement. The method requires a minimum of field work and estimates the quality value of habitat based on the presence, absence or condition of a few critical variables. The quality value is multiplied by habitat area to obtain comparable units for alternative evaluations. Habitat evaluations are based on habitat types, but can be made species specific for protected species or target organisms.

The HES method (COE 1980) is more specific than the Hamor method and requires more detailed information. The calculation of a standardized unit (Habitat Quality Index) allows for the comparison of impacts to dissimilar habitats. The evaluation of habitat quality can be made with relative ease in the field. The method evaluates key variables for specific habitat types and does not directly evaluate the habitat value for specific target species.

The handbook developed by Baskett et al. (1980) represents a hybrid of the Hamor and HES approaches. Evaluation criteria are established for specific target species by habitat type. Habitat unit values are calculated by numerical scoring at habitat characteristics. Project impacts to specific species can be evaluated by performing calculations with and without the project.

The method developed by Whitaker and McCuen (1975) and the Habitat Evaluation Procedures (HEP) of the USFWS (1980) are similar. Both methods evaluate habitat quality by use of a computer model, but the data requirements for the Whitaker and McCuen procedure are less. Only limited field work is required, and the method relies heavily on professional judgement. The evaluation method uses land use and a vegetation condition assessment to estimate the habitat value for two groups of wildlife species: woodland and open land. Species specific evaluations are not included in the procedure.

HEP (USFWS 1980) is the most comprehensive and information intensive of the habitat evaluation methods. Field investigations and computer modeling is required by the method. The procedure calculates the number of Habitat Units for a target species based on the area of available habitat and the suitability of the habitat to the target species.

Protected Species. The presence of a protected species from either a federal or state list can significantly impact the feasibility, cost and schedule of a project. While an initial assessment of the probability of the presence of a protected species can be quickly conducted in the preliminary screening step, a complete analysis of potential impacts can be extremely involved. Therefore, a series of procedures are generally used

to evaluate this resource including range maps, reported sightings, habitat evaluations, seasonal presence or requirements and direct sampling.

Table 9-16 is the federal list of protected species associated with wetlands. Tables 9-17 to 9-24 list protected species for each Region IV state. However, the list of species and status of species are subject to change. Applicants are encouraged to coordinate all protected species investigations with the appropriate state and federal agencies (Section 9.6).

Table 9-16. United States Department of Interior Fish and Wildlife Service List of Wetland-dependent Endangered (E) and Threatened (T) Species Endemic to Region IV.

	Status	Distribution
Mammals		
Florida panther (*Felis concolor coryi*)	E	AL, FL, GA, MS, SC,TN
Birds		
Mississippi sandhill crane (*Grus canadensis pulla*)	E	MS
Bald eagle (*Haliaeetus leucocephalus*)	E	AL, FL, GA, KY,MS,NC, SC, TN
American peregrine falcon (*Falco peregrinus*)	E	AL, FL, GA, KY, NC,SC, TN
Bachman's warbler (*Vermivora bachmanii*)	E	AL, FL, GA, KY, MS,NC, SC, TN
Everglade kite (*Rostrhamus sociabilis plumbeus*)	E	FL
Cape Sable seaside sparrow (*Ammospiza maritima mirabilis*)	E	FL
Dusky seaside sparrow (*Ammospiza maritima nigrescens*)	E	FL
Ivory billed woodpecker (*Campephilus principalis*)	E	FL
Brown pelican (*Pelecanus occidentalis carolinensis*)	E	AL, FL, GA, MS, NC,SC
Amphibians and Reptiles		
American alligator (*Alligator mississippiensis*)	E	AL, GA, MS, NC, SC
American alligator ((*Alligator mississippiensis*)	T[1]	FL, GA, SC
Pine barrens treefrog (*Hyla andersoni*)	E	FL
Fish		
Bayou darter (*Etheostoma rubrum*)	T	MS
Okaloosa darter (*Etheostoma okaloosae*)	E	FL

[1] Alligator populations are threatened in Florida and coastal areas of Georgia and South Carolina.

Source: Adapted from the United States Fish and Wildlife Service List of Threatened and Endangered Species of Fish and Wildlife (50 CFR 17.11)

Table 9-17. List of Wetland-Dependent Species in Alabama of Endangered Status (E) Threatened Status (T) and Special Concern Status (S).

	Status
Mammals	
Florida black bear (*Ursus americanus floridanus*)	E
Florida panther (*Felis concolor coryi*)	E
Southeastern shrew (*Sorex longirostis*)	S
Marsh rabbit (*Sylvilagus palustris palustris*)	S
Bayou grey squirrel (*Sciurus carolinensis fuliginosus*)	S
Meadow Jumping Mouse (*Zapus hudsonius americanus*)	S
Fish	
Slackwater darter (*Etheostoma boschungi*)	T
Broadstripe shiner (*Notropis euryzonus*)	S
Brindled madtom (*Noturus miurus*)	S
Birds	
Bald eagle (*Haliaeetus leucocephalus*)	E
Osprey (*Pandion haliaetus*)	E
Peregrine falcon (*Falco peregrinus*)	E
Bachman's warbler (*Vermivora bachmanii*)	E
Ivory-billed woodpecker (*Campephilus principalis*)	E
Little blue heron (*Florida caerulea*)	S
Wood stork (*Mycteria americana*)	S
Swallow-tailed kite (*Elanoides forficatus*)	S
Sandhill crane (*Grus canadensis*)	S
Amphibians and Reptiles	
Flatwoods salamander (*Ambystoma cingulatum*)	E
American alligator (*Alligator mississippiensis*)	T
Alabama red-bellied turtle (*Pseudemys alabamensis*)	T
River frog (*Rana heckscheri*)	S
Greater siren (*Siren lacertina*)	S
Florida green water snake (*Natrix cyclopion floridana*)	S
North Florida black swamp snake (*Seminatrix pygaea pygaea*)	S

Source: Adapted from Boschung, 1976.

Table 9-18. List of Wetland-Dependent Species in Florida of Endangered Status (E) Threatened Status (T) and Special Concern Status (S)

	Status
Mammals	
Pallid beach mouse (*Peromyscus polionotus decoloratus*)	E
Florida panther (*Felis concolor coryi*)	E
Choctawhatchee beach mouse (*Peromyscus polionotus allopyhrys*)	T
Perdido Bay beach mouse (*Peromyscus polionotus trisyllepsis*)	T
Florida black bear (*Ursus americanus floridanus*)	T
Everglades mink (*Mustela vison evergladensis*)	T
Fish	
Okaloosa darter (*Etheostoma okaloosae*)	E
Crystal darter (*Ammocrypta asprella*)	T
Saltmarsh topminnow (*Fundulus jenkinsi*)	S
Birds	
Wood stork (*Mycteria americana*)	E
Everglade kite (*Rostrhamus sociabilis*)	E
Peregrine falcon (*Falco peregrinus*)	E
Ivory-billed woodpecker (*Campephilus principalis*)	E
Bachman's warbler (*Vermivora bachmanii*)	E
Dusky seaside sparrow (*Ammospiza maritima nigrescens*)	E
Cape Sable seaside sparrow (*Ammospiza maritima mirabilis*)	E
Eastern brown pelican (*Pelecanus occidentalis carolinensis*)	T
Bald eagle (*Haliaeetus leucocephalus*)	T
Audubon's caracara (*Caracara cheriway auduboni*)	T
Florida sandhill crane (*Grus canadensis*)	T
Roseate tern (*Sterna dougallii*)	T
Little blue heron (*Florida caerulea*)	S
Snowy egret (*Egretta thula*)	S
Louisiana heron (*Hydranassa tricolor*)	S
Amphibians and Reptiles	
Pine barrens treefrog (*Hyla andersoni*)	E
Florida brown snake (*Storeria dekayi victa*)	T
American alligator (*Alligator mississippiensis*)	S

[1] Classified as endangered on the federal list.

Source: Adapted from Pritchard, 1978.

Table 9-19. List of Wetland-Dependent Species in Georgia of Endangered Status (E) Threatened Status (T), Rare Status (R) or Unusual Status (U)

	Status
Mammals	
Florida panther (*Felis concolor coryi*)	E
Fish	
none	
Birds	
Ivory-billed woodpecker (*Campephilus principalis*)	E
Peregrine falcon (*Falco peregrinus*)	E
Southern bald eagle (*Haliaeetus leucocephalus leucocephalus*)	E
Brown pelican (*Pelecanus occidentalis carolinensis*)	T
Bachman's warbler (*Vermivora bachmanii*)	E
Amphibians and Reptiles	
American alligator (*Alligator mississippiensis*)	E/T[1]

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[1] American alligator is an endangered species along the Georgia coastal plain and a threatened species in coastal areas.

Source: Adapted from Odom et al. (eds). 1977.

Table 9-20. List of Wetland-Dependent Species in Kentucky of the Endangered Status (E) Threatened Status (T), or Rare Status (R)[1].

	Status
Mammals	
Cougar (*Felis concolor*)	E
River otter (*Lutra canadensis*)	R
Black bear (*Ursus americanus*)	R
Swamp rabbit (*Sylvilagus aquaticus*)	R
Fish	
Mud darter (*Etheostoma asprigene*)	R
Birds	
Bald eagle (*Haliaeetus leucocephalus*)	E
American peregrine falcon (*Falco peregrinus*)	E
Osprey (*Pandion haliaetus*)	R
Mississippi kite (*Ictinia misisippiensis*)	R
Sandhill crane (*Grus canadensis*)	R
Amphibians and Reptiles	
Western lesser siren (*Siren intermedia*)	R
Western bird voiced treefrog (*Hyla avivoca avivoca*)	R
Green treefrog (*Hyla cinera cinerea*)	R
Western mud snake (*Farancia abacura reinwardti*)	R
Green water snake (*Natrix cyclopion cyclopion*)	R
Broad-banded water snake (*Natrix fasciata confluens*)	R
Alligator snapping turtle (*Macroclemys temmincki*)	R
Slider (*Chrysemys concinna hieroglyphica*)	R

---

[1] Rare species are protected (except rats, mice and shrews) by Kentucky statutes unless there is a regulation permitting them to be taken.

Source: Adapted from Parker and Dixon. 1980.

Table 9-21. List of Wetland-Dependent Species in Mississippi of the Endangered Status (E) and Threatened Status (T).

	Status
Mammals	
Florida panther (Felis concolor coryi)	E
Black bear (Ursus americanus)	T
Fish	
Bayou darter (Etheostoma rubrum)	E
Crystal darter (Ammocrypta asprella)	E
Birds	
Mississippi sandhill crane (Grus canadensis pulla)	E
Bald eagle (Haliaeetus leucocephalus)	E
Peregrine falcon (Falco peregrinus)	E
Bachman's warbler (Vermivora bachmanii)	E
Ivory-billed woodpecker (Campephilus principalis)	E
Amphibians and Reptiles	
Rainbow snake (Farancia erytrogramma)	E
American alligator (Alligator mississippiensis)	E
Black-nobbed sawback turtle (Graptemys nigrinoda)	E
Ringed sawback turtle (Graptemys oculifera)	T
Yellow-blotched sawback turtle (Graptemys flavimaculata)	T

Source: Adapted from the Mississippi Department of Wildlife Conservation Bureau of Fisheries and Wildlife, Public Notice No. 2156.

Table 9-22. List of Wetland Dependent Species in North Carolina of the Endangered Status (E) and Threatened Status (T)

	Status
Mammals	
Eastern couger (Felis concolor cougar)	E
Fish None	
Birds	
American peregrine falcon (Falco peregrinus)	E
Artic peregrine falcon (Falco peregrinus tundris)	E
Bachman's warbler (Vermivora bachmanii)	E
Bald eagle (Haliaeetus leucocephalus)	E
Ivory-billed woodpecker (Campephilus principalis)	E
Brown pelican (Pelecanus occidentalis)	E
Amphibians and Reptiles	
American alligator (Alligator mississippiensis)	E

Source: Adapted from Parker and Dixon, 1980.

Table 9-23. List of Wetland Dependent Species in South Carolina of the Endangered Status (E) and Threatened Status (T).

	Status
Mammals	
Eastern cougar (Felis concolor cougar)	E
Fish	
None	
Birds	
American peregrine falcon (Falco peregrinus)	E
Bachman's warbler (Vermivora bachmanii)	E
Eastern brown pelican (Pelecanus occidentalis carolinensis)	E
Golden eagle (Aquila chrysaetos)	E
Swallow-tailed kite (Elanoides forficatus)	E
Wood stork (Mycteria americana)	T
Cooper's hawk (Accipiter cooperii)	T
American osprey (Pandion haliaetus)	T
Amphibians and Reptiles	
Pine barrens treefrog (Hyla andersoni)	E
American alligator (Alligator mississippiensis)	E

Source: Adapted from Parker and Dixon, 1980.

Table 9-24. List of Wetland Dependent Wildlife Species in Tennessee of the Endangered Status (E) and Threatened Status (T)

	Status
Mammals	
Eastern cougar (Felis concolor cougar)	E
Florida panther (Felis concolor coryi)	E
River otter (Lutra canadensis)	T
Fish	
Slackwater darter (Etheostoma boschungi)	T
Trispot darter (Etheostoma trisella)	T
Birds	
Bachman's warbler (Vermivora bachmanii)	E
Peregrine falcon (Falco peregrinus)	E
Bald eagle (Haliaeetus leucocephalus)	E
Ivory-billed woodpecker (Campephilus principalis)	E
Brown pelican (Pelecanus occidentalis)	E
Mississippi kite (Ictinia misisippiensis)	E
Osprey (Pandion haliaetus)	E
Marsh hawk (Circus cyaneus hudsonius)	T
Black-crowned night heron (Nycticorax nycticorax)	T
Amphibians and Reptiles	
Western pigmy rattlesnake (Sistrurus miliarius streckeri)	T

Source: Adapted from Eagar and Hatcher, 1980.

9.5 HYDROLOGIC AND HYDRAULIC ANALYSES

Hydrologic and hydraulic characteristics of the freshwater wetland must be considered in evaluating the use of the wetland for wastewater management. This section presents a method for estimating water flows, velocities, depth, residence times, and areas-of-inundation in wetlands under natural conditions and after the application of wastewater. The method considers the following wetland types (see Table 2-1) and geometric cross-sections:

1. Closed Hydrologic System (e.g., cypress domes, Carolina bays, pocosins)
2. Open Hydrologic System with identifiable stream channel (e.g., bottomland hardwood swamp)
   a. Channel with rectangular cross-section
   b. Channel with trapezoidal cross-section
   c. Channel with triangular cross-section
3. Open Hydrologic System with no identifiable stream channel (e.g., marsh, cypress stands)
   a. Wetland with rectangular cross-section
   b. Wetland with triangular cross-section
4. Open Hydrologic System with outflow controlled by some structure.

The method presented in this section is designed as a screening technique to assess the magnitude of the effects of a wastewater discharge to a wetland. The method should be used with extreme care in karst topography or in wetlands with unsaturated soils. The method has not been verified and continuing efforts need to be made to evaluate the method using newly available data on wetland hydrology and hydraulics. Care should be taken to utilize conservative assumptions in using these techniques.

The hydrology and hydraulic analysis methodology includes three levels of analysis: a basic analysis; a seasonal analysis; and a refined analysis. The basic analysis is used as an initial screening procedure with a minimum of data. The seasonal analysis is used when wastewater is to be applied at varying rates through the year or when seasonal variability in hydrology and climate are known to occur in the wetland. The refined analysis is used for unique or sensitive wetlands or when basic and/or seasonal analyses indicate the potential for large changes in wetland hydrology due to wastewater application.

A basic analysis is performed to estimate the changes in annual average wetland hydrologic characteristics based on published data available on climatology, topography, and geohydrology and site-specific data obtained on a one-day survey of the wetland. The survey would include identification of channel width and bankheight, vegetation distribution in the wetland, and a hand-level determination of the elevation change across the wetland perpendicular to the general topographic slope of the wetland.

The seasonal analysis is performed to estimate changes in wetland hydrologic characteristics based on seasonal data. Seasonal analysis methods are the same as basic analysis methods with the exception that the seasonal analysis requires monthly data from published sources in addition to the site-specific data obtained for the basic analysis.

A refined analysis should be performed if the proposed wetland system is unique or sensitive, or if an evaluation of the basic or seasonal hydrologic analyses indicates that the wetland would be significantly affected by the wastewater application. A refined analysis also should be performed if the hydraulic characteristics are unsuitable for necessary wastewater pollutant removals. Data collection could include at least one year of measurements of surface water inflows and outflows, precipitation, evapotranspiration, water surface elevations, groundwater elevations at several locations, and flow path and velocity measurements using tracer studies at various locations in the wetland.

Depth, velocity and area-of-inundation data collected for the refined analysis would be compared with predictions made using the basic or seasonal analysis methodologies (water budget and Manning's equation). Inputs to these analyses would be adjusted so that they would reproduce observed field data under existing flow conditions. These analyses would then be performed for conditions present with the application of wastewater to the wetland.

9.5.1 Basic Analysis

A basic wetland hydraulic and hydrologic analysis is performed using annual averages of hydrologic and climatic data. The analysis is designed to assess the potential for a significant change in hydrology resulting from the application of wastewater to the wetland. The analysis is useful as a preliminary screening tool to identify situations in which the wastewater application could cause major changes in hydrology. Because it is based on annual averages it ignores important wetland characteristics such as response under wet and dry conditions and hydroperiod. If these features are of critical importance, a seasonal analysis is required.

A flow chart outlining the basic analysis is presented in Figure 9-5. The analysis is performed in three steps. The first step is to consider the wetland in its current state; that is, unaltered by any wastewater application. The second step is to consider the wetland hydrology and hydraulics with the application of a known wastewater volume. The third step is to compare hydrologic and hydraulic characteristics of flows in the wetland prior to and with the wastewater application. Depending on the magnitude of the changes, additional seasonal or refined analyses may be required.

Both steps one and two in the analysis are conducted in two parts. First, a water budget is calculated for the wetland to determine water inflows and outflows. Second, depths of flow, velocities, area-of-inundation, and residence time are estimated, using Manning's equation.

The following discussion describes the water budget analysis, the Manning's equation analysis, the data requirements and the application of the analysis methodology to various wetland situations.

Water Budget Analysis

A water budget analysis is performed to estimate surface water flows in the wetland. The water budget equation relates the change in water volume stored in the wetland over a specified time period to the difference in water volume inflows to and outflows from the wetland. The water budget equation may be written as:

$$\Delta S = P + Q_1 + Q_L + G_1 + W - Q_2 - G_2 - E$$

where: ΔS = volume change of water stored in the wetland during a specified time interval, t

t = time interval over which water budget is calculated

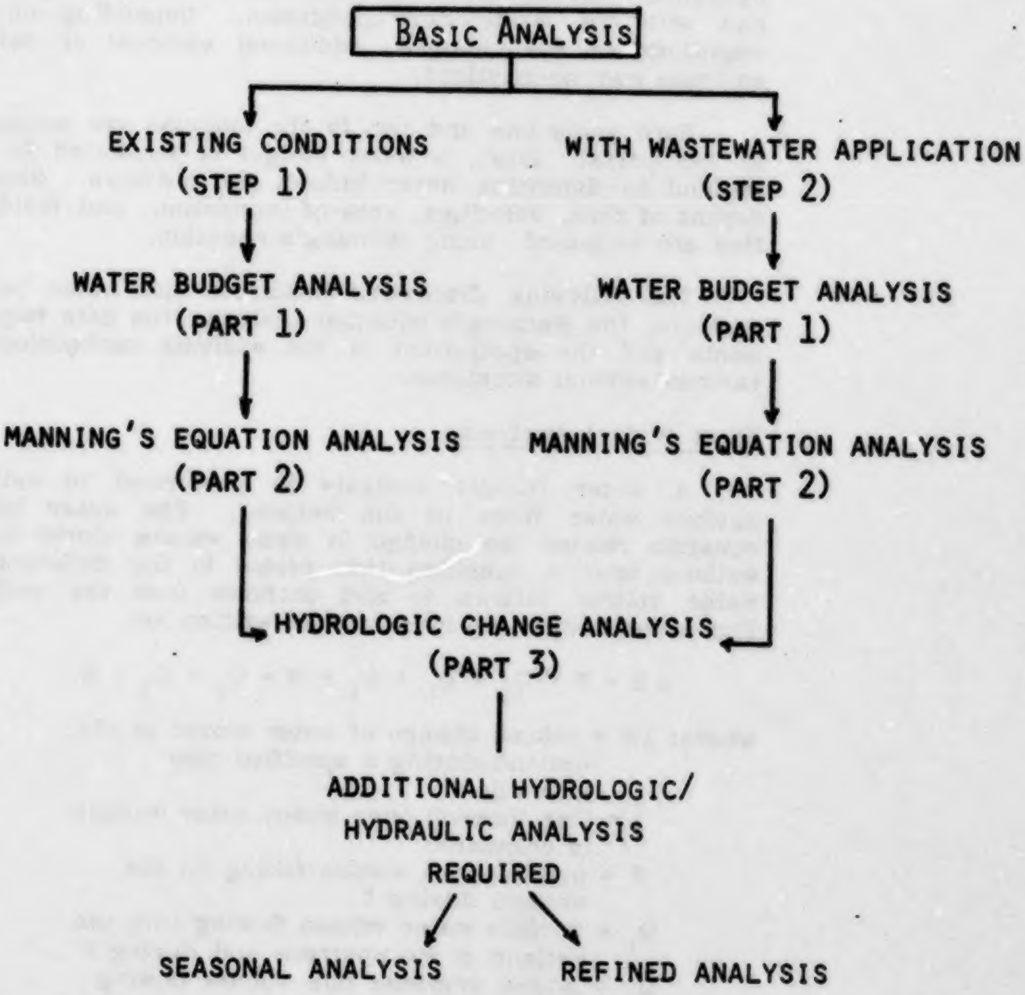
P = precipitation volume falling on the wetland during t

Q_1 = surface water volume flowing into the wetland at its upstream end during t

Q_L = lateral overland flow volume flowing into the wetland during t

G_1 = groundwater volume flowing into the wetland during t

Figure 9-5. Flow chart for a basic analysis.


BASIC ANALYSIS
EXISTING CONDITIONS (STEP 1)
WITH WASTEWATER APPLICATION (STEP 2)
WATER BUDGET ANALYSIS (PART 1)
WATER BUDGET ANALYSIS (PART 1)
MANNING'S EQUATION ANALYSIS (PART 2)
MANNING'S EQUATION ANALYSIS (PART 2)
HYDROLOGIC CHANGE ANALYSIS (PART 3)
ADDITIONAL HYDROLOGIC/ HYDRAULIC ANALYSIS REQUIRED
SEASONAL ANALYSIS
REFINED ANALYSIS

W = wastewater volume applied to the wetland during t
Q_2 = surface water volume flowing out of the wetland at its downstream end during t
G_2 = groundwater volume flowing out of the wetland during t
E = evapotranspiration volume leaving the wetland during t

In a basic analysis, site-specific data on the components of the water budget generally will not be available. To determine surface water outflows from the wetland it is necessary to perform the water budget analysis assuming a time interval of one year; that is, an annual water budget. Furthermore, the assumption is made that on an annual basis there is no change in the volume of water stored in the wetland (i.e., $\Delta S = 0$). Consequently, on an annual basis the inputs to a wetland are assumed to equal the outputs from the wetland:

$$P + Q_1 + Q_L + G_1 + W = E + Q_2 + G_2$$

Manning's Equation Analysis

Manning's equation is commonly used to characterize flow conditions in open channels and in flood plains adjacent to the channel. The equation relates discharge (Q) to wetland slope (S), the roughness of the channel or wetland (n), the cross-sectional area of flow (A), and the length of ground surface in contact with the water being discharged (i.e., wetted perimeter, P). The equation is commonly written as:

$$Q = 1.49\, n^{-1}\, A\, R^{2/3}\, S^{1/2}$$

where R is the hydraulic radius which is equal to the area divided by the wetted perimeter (A/P). Detailed discussions of the assumptions behind the equation and in the application of the equation are provided in standard open channel flow textbooks (e.g., Chow 1959; Henderson 1966).

Manning's equation is strictly applicable only under conditions of uniform flow in which the depth, water cross-sectional area, velocity, and discharge in a channel reach are constant. Uniform flow also requires that the energy gradient, water surface, and channel bottom have the same slope. In natural streams and particularly wetlands, uniform flow rarely exists; however, the uniform flow condition is often used in computations of flow characteristics in natural streams. Consequently, the use of Manning's equation must be viewed as a means of approximating flow conditions in wetlands and is presented here as a simple mathematical tool for screening hydrologic changes in wetlands due to the application of wastewater.

The Manning's equation analysis is completed to estimate the depth of flow in the wetland for a known discharge (Q), slope (S), roughness coefficient (n), and cross-sectional geometry. The discharge is determined in the water budget analysis. The slope and cross-section geometry are determined from topographic maps and/or a site survey. Channel or wetland cross-section geometries discussed in this handbook include rectangular, trapezoidal, and triangular shapes. A step-by-step discussion of the Manning's equation analysis is provided later in this section under the heading "Application to Various Wetland Hydrologic Situations."

Data Requirements

The preceding parts of Section 9.5.1 discussed a water budget analysis to determine flows within a wetland and Manning's equation analysis to estimate depths associated with these flows. The data required to support the water budget and Manning's equation analyses are tabulated in Table 9-25. Data are either obtained from published sources, from government data bases, or from a one-day wetland site survey.

A basic analysis requires a one-day site survey to obtain data on wetland area, vegetation distribution, detailed topography, and channel/wetland geometry. Wetland area and vegetation distribution should be noted on a topographic map during the walk-through survey of the site. For a closed hydrologic system, vegetation should be studied to determine the approximate location of the annual average area-of-inundation. This determination will require the services of a wetland ecologist. Photographs of the wetland should be taken for reference purposes. These photographs can then be used in conjunction with Chow (1959) and Arcement and Schneider (1984) to estimate values for Manning's-n.

The main activity of the one-day site survey is to produce a detailed map of the wetland topography. A minimum of five transects should be made across the wetland perpendicular to the slope of the wetland. Elevations at increments of 0.5 feet should be determined in the transects. Elevations should be determined relative to an arbitrary datum such as the upstream- or downstream-end of the wetland. Distances along the transect can be measured either by pacing or with a tape measure. Elevations should be measured with a surveyor's rod and a hand level or transit. Transect paths should be across portions

Table 9-25. Data requirements and sources for a basic analysis.

Water Budget Analysis Component	Source
Precipitation (P)	Figure 9-10 or Local Climatological Data Annual and monthly summaries available from the NOAA National Climatic Data Center, Asheville, NC.
Surface Water Inflow (Q_1)	US Geological Survey Water Resources Data for the state of interest
Wastewater Application Flowrate (W)	Specified in system design
Evapotranspiration (E)	Figure 9-11
Surface Water Outflow (Q_2)	Calculated as residual in the water budget analysis
Groundwater Flow (G_1, G_2)	Engineering judgement based on: County Soil Surveys published by Soil Conservation Service Geological and geohydrological reports by US Geological Survey and State Geological Survey
Wetland Area (A_w)	Topographic Maps and Site Survey
Drainage Areas	Topographic Maps
Average Area-of-Inundation (closed hydrologic systems only)	Site Survey-vegetation distribution/type

Manning's Equation Analysis Component	Source
Manning's-n (n)	Site Survey Table 9-5
Wetland Slope (S)	Topographic map or site survey
Channel/Wetland Geometry	Site survey

of the wetland which are representative of the wetland. Particular attention should be paid to detailing the channel geometry and the wetland geometry (shape and dimensions). A detailed topographic map and cross-section diagrams should be prepared using data from the transects.

Application to Various Wetland Hydrologic Situations

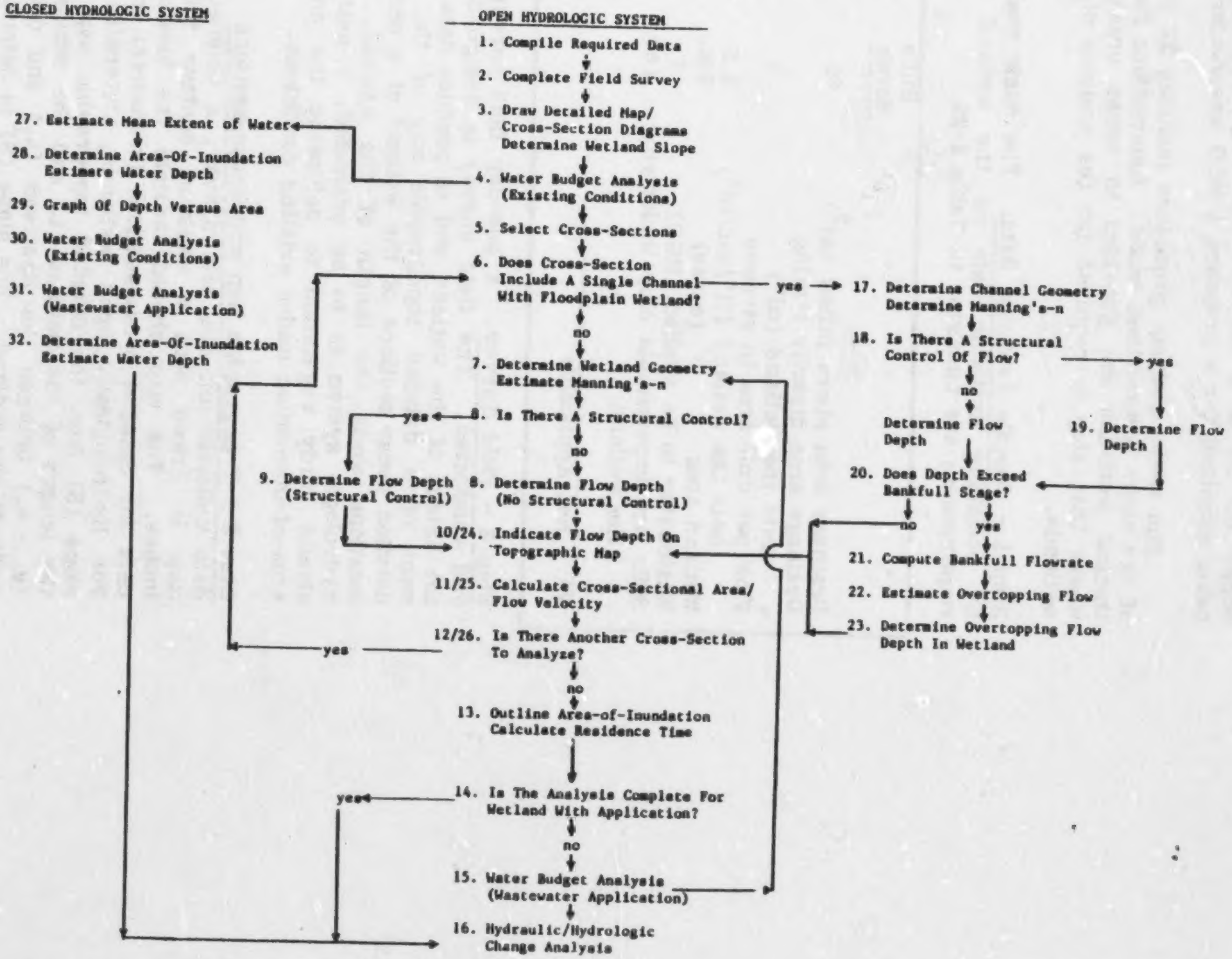
Water budget analysis and Manning's equation analysis may be used to predict changes in wetland hydrology resulting from the application of wastewater to the wetland. Wetland hydrologic characteristics evaluated in a basic analysis include flow, velocity, residence time, depth, and area-of-inundation. These characteristics are estimated for conditions existing prior to the wastewater application and while wastewater is being applied to the wetland. The changes in depth, velocity and area-of-inundation are then used to assess the significance of the hydrologic change on wetland ecology. The assessment will result in a finding of (1) minimum change with no additional analysis required; (2) intermediate change indicating a need for completing monthly or seasonal water budget and Manning's-n analyses; or (3) major change indicating a need for the collection of significant site-specific data to support calibration of the water budget and Manning's-n analysis models.

The application of the basic analysis is described in this part of the handbook. A flowchart of the basic analysis is presented in Figure 9-6. The discussion which follows refers directly to this flowchart. The flowchart includes the following wetland situations: (1) a closed hydrologic system; (2) an open hydrologic system with no identifiable channel; (3) an open hydrologic system with a single identifiable stream channel; and (4) an open hydrologic system with a single identifiable channel and flow regulated by some kind of structural control.

It should be noted that each wetland has unique features which may deviate from these four wetland situations. Also, a single wetland may have more than one cross-section type in different areas. The manager or engineer performing a basic analysis must use some judgement in identifying the wetland situation which most closely approximates the wetland to be evaluated. The more the actual wetland differs from the wetland situation classification, the greater will be the potential for erroneous results from the analysis.

For purposes of illustration, the basic analysis procedure will be applied to two hypothetical wetlands located near Atlanta, GA: Bill's Marsh and Soggy Bottom. Bill's Marsh is a 300-acre hydrologically open wetland being

Figure 9-6. Detailed flow chart for the wetland hydrologic and hydraulic analyses.


CLOSED HYDROLOGIC SYSTEM
OPEN HYDROLOGIC SYSTEM
1. Compile Required Data
2. Complete Field Survey
3. Draw Detailed Map/ Cross-Section Diagrams Determine Wetland Slope
4. Water Budget Analysis (Existing Conditions)
5. Select Cross-Sections
6. Does Cross-Section Include A Single Channel With Floodplain Wetland?
yes
no
7. Determine Wetland Geometry Estimate Manning's-n
8. Is There A Structural Control?
yes
no
9. Determine Flow Depth (Structural Control)
8. Determine Flow Depth (No Structural Control)
10/24. Indicate Flow Depth On Topographic Map
11/25. Calculate Cross-Sectional Area/ Flow Velocity
12/26. Is There Another Cross-Section To Analyze?
yes
no
13. Outline Area-of-Inundation Calculate Residence Time
14. Is The Analysis Complete For Wetland With Application?
yes
no
15. Water Budget Analysis (Wastewater Application)
16. Hydraulic/Hydrologic Change Analysis
17. Determine Channel Geometry Determine Manning's-n
18. Is There A Structural Control Of Flow?
yes
no
Determine Flow Depth
19. Determine Flow Depth
20. Does Depth Exceed Bankfull Stage?
no
yes
21. Compute Bankfull Flowrate
22. Estimate Overtopping Flow
23. Determine Overtopping Flow Depth In Wetland
27. Estimate Mean Extent of Water
28. Determine Area-Of-Inundation Estimate Water Depth
29. Graph Of Depth Versus Area
30. Water Budget Analysis (Existing Conditions)
31. Water Budget Analysis (Wastewater Application)
32. Determine Area-Of-Inundation Estimate Water Depth

examined for a proposed 1 MGD wastewater discharge. Soggy Bottom is a 300-acre hydrologically closed wetland being examined for a proposed 1 MGD wastewater discharge.

The basic analysis procedure includes 32 steps. Each of the steps is described below. Illustrations for the hypothetical wetlands are provided in boxes under each step where that step is required for the analysis of one of the wetlands.

Step 1 - Compile Available Data. The basic analysis begins by compiling available data on the wetland site. Data requirements are tabulated in Table 9-25.

	Bill's Marsh	Soggy Bottom
Drainage area above inflow (mi^2)	50	NA
Drainage area directly flowing into the wetland (mi^2)	1	1
Flow per unit area in streams near the wetland ($ft^3/sec/mi^2$)	1.5	1.5
Wetland area (acres)	300	300
Wastewater to be applied (MGD)	1	1
Soils are impermeable clay underlying the wetland	Yes	No

NA - Not Applicable

Step 2 - Field Survey. A one-day field survey is designed and conducted. The field survey is designed to delineate the extent of the wetland and to produce data for development of a detailed topographic map of the wetland and detailed cross-sections of the wetland at a minimum of five locations along the length of the wetland. If a closed hydrologic system is to be evaluated, a wetland ecologist should study vegetation to determine the annual average area-of-inundation under existing conditions.

Step 3 - Topographic Map and Cross-sections. Based on data collected on the site survey, a detailed topographic map is drawn with a maximum contour interval of six inches. The map should indicate the locations at which data for detailed cross-sections (transects) were collected. For hydrologically open wetlands, determine the wetland slope (S) from the detailed topographic map by measuring the length of the wetland (L) and the change in elevation ($e_1 - e_2$) between the upstream (e_1) and downstream (e_2) ends of the wetland. The slope (S) is determined by: $S = (e_1 - e_2)/L$

Also, for hydrologically open systems, for each location where cross-section (transect) data are collected during the field survey, draw a cross-section diagram.

Figures 9-7 and 9-8 show detailed topographic maps prepared for Bill's Marsh and Soggy Bottom.

For Bill's Marsh

Wetland Slope (S) = $(e_1 - e_2)/L$

$e_1 = 1.0$ ft

$e_2 = 0.0$ ft

$L = 3600$ ft

Therefore, $S = (1.0 - 0.0)/3600 = 0.0003$

Figure 9-9 shows cross-section diagrams at the three locations which were surveyed: A-A', B-B', and C-C'. The actual ground features and the assumed geometric shape for each of the cross-sections are indicated in the figure.

For Soggy Bottom

Wetland slope(s) and wetland cross-section diagrams are not required since this is a hydrologically closed system.

Step 4 - Water Budget Analysis (Existing Conditions). If the wetland is a hydrologically closed system, such as Soggy Bottom, skip to Step 27; otherwise compute an annual water budget under existing conditions in the wetland. The analysis will result in estimates of the average annual surface water inflow to the wetland (Q_1) and an average annual surface water outflow from the wetland (Q_2). Flowrates for points in the wetland between the upstream end and the downstream end of the wetland should be estimated by linear interpolation. The values of estimated flow should be entered on the cross-section diagrams and Form 9-A, which is included at the end of Section 9.5. For Bill's Marsh, a completed Form 9-A is included as Table 9-27 and cross-sections are included as Figure 9-9.

To determine surface water outflow on an annual basis, all of the other components of the water budget equation must be estimated from available data sources. Estimation procedures for each of the components in the annual water budget equation are presented in the following paragraphs.

Also, for hydrologically open systems, for each location where cross-section (transect) data are collected during the field survey, draw a cross-section diagram.

Figures 9-7 and 9-8 show detailed topographic maps prepared for Bill's Marsh and Soggy Bottom.

For Bill's Marsh

Wetland Slope (S) = $(e_1 - e_2)/L$

$e_1 = 1.0$ ft

$e_2 = 0.0$ ft

$L = 3600$ ft

Therefore, $S = (1.0 - 0.0)/3600 = 0.0003$

Figure 9-9 shows cross-section diagrams at the three locations which were surveyed: A-A', B-B', and C-C'. The actual ground features and the assumed geometric shape for each of the cross-sections are indicated in the figure.

For Soggy Bottom

Wetland slope(s) and wetland cross-section diagrams are not required since this is a hydrologically closed system.

Step 4 - Water Budget Analysis (Existing Conditions). If the wetland is a hydrologically closed system, such as Soggy Bottom, skip to Step 27; otherwise compute an annual water budget under existing conditions in the wetland. The analysis will result in estimates of the average annual surface water inflow to the wetland (Q_1) and an average annual surface water outflow from the wetland (Q_2). Flowrates for points in the wetland between the upstream end and the downstream end of the wetland should be estimated by linear interpolation. The values of estimated flow should be entered on the cross-section diagrams and Form 9-A, which is included at the end of Section 9.5. For Bill's Marsh, a completed Form 9-A is included as Table 9-27 and cross-sections are included as Figure 9-9.

To determine surface water outflow on an annual basis, all of the other components of the water budget equation must be estimated from available data sources. Estimation procedures for each of the components in the annual water budget equation are presented in the following paragraphs.

Figure 9-7. Detailed topographic map for Bill's Marsh.

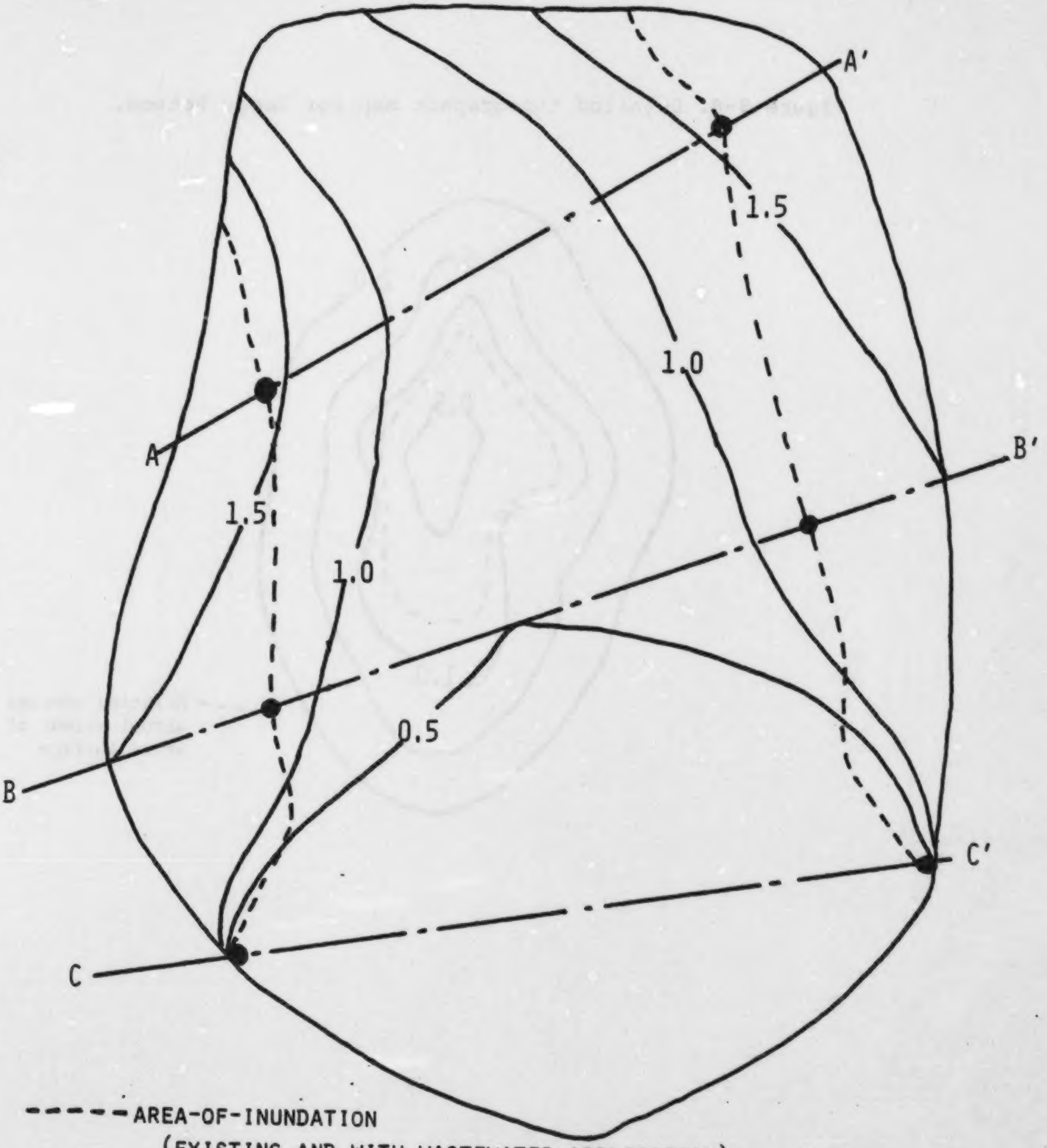

A'
1.5
1.0
A
1.5
1.0
B'
B
0.5
C'
C
AREA-OF-INUNDATION
(EXISTING AND WITH WASTEWATER APPLICATION)

Figure 9-8. Detailed topographic map for Soggy Bottom.

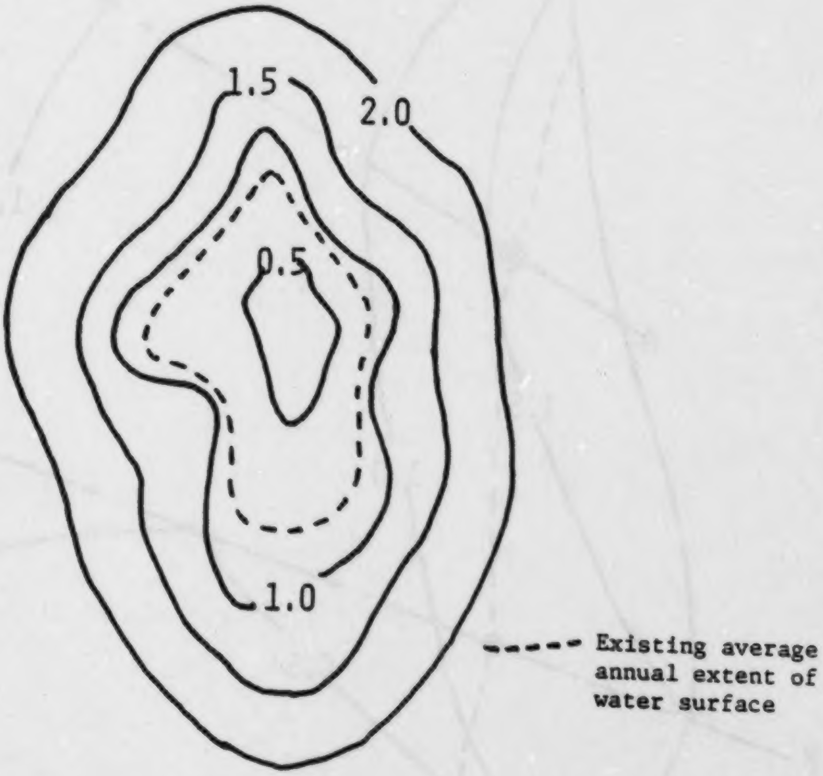

1.5
2.0
0.5
1.0
Existing average annual extent of water surface

Figure 9-9. Cross-section diagrams for Bill's Marsh.

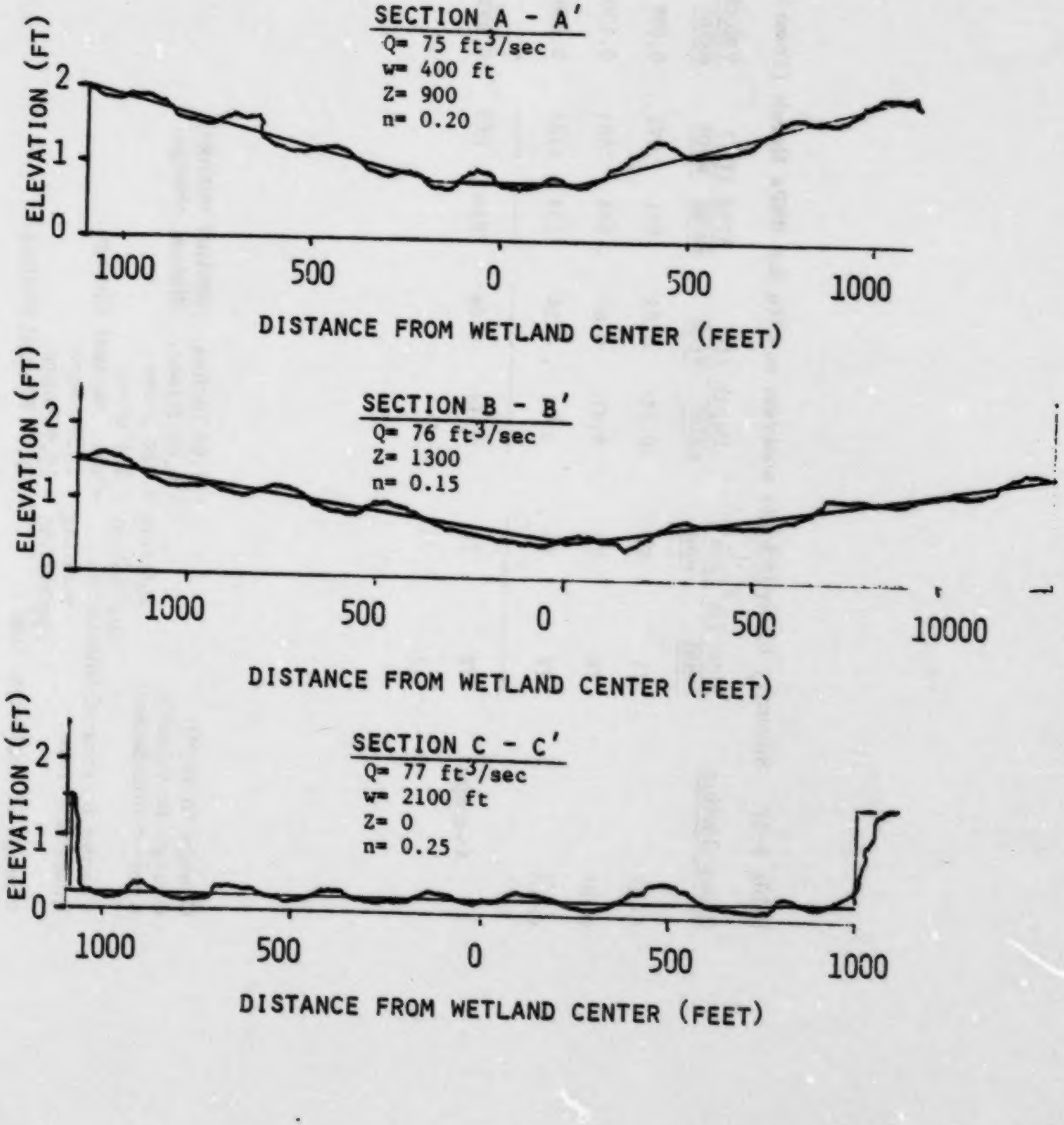


Table 9-27. Summary of hydrologic analysis results for Bill's Marsh (Form 9-A).

Cross-Section	Flow (ft^3/sec)		Depth (ft)		Area (ft^2)		Velocity (ft/sec)	
	exist	appl	exist	appl	exist	appl	exist	appl
A-A'	75	77	0.84	0.84	971	971	0.077	0.077
B-B'	76	78	0.67	0.67	584	584	0.130	0.130
C-C'	77	79	0.54	0.54	1134	1134	0.068	0.068
Average	76	78	0.68	0.68	896	896	0.092	0.092

Change in depth = 0.00 inches. Minimal change.
Change in velocity = 0.00 ft/sec. Minimal change.
Area-of-inundation: existing = 230 acres
application = 230 acres
Change in area-of-inundation = 0%. Minimal Change.
Residence Time: existing = 10.9 hours
application = 10.9 hours
Change in residence time = 0%. Minimal change.

Precipitation (P).

1. Determine the area of the wetland (A_w):
   - a. Obtain topographic map(s) which include(s) the entire wetland
   - b. Outline the wetland area
   - c. Measure the wetland area using a planimeter or other drainage area measurement method.

2. Find the location of the wetland in Figure 9-10, and read the annual precipitation off of the map, or contact the nearest meteorological station to obtain annual precipitation.

3. Convert precipitation in inches to a volume by multiplying by the area of the wetland.

For Bill's Marsh

1. Wetland area was determined to be 300 acres using a planimeter.

2. From Figure 9-10, annual precipitation is estimated to be 48 inches.

3. Convert to a volume:

$$P = 48 \text{ in/yr} \times 1 \text{ ft/12in} \times 300 \text{ acres} \times 43560 \text{ ft}^2\text{/acre}$$

$$P = 52.3 \times 10^6 \text{ ft}^3\text{/yr}$$

Surface Water Inflow (Q_i).

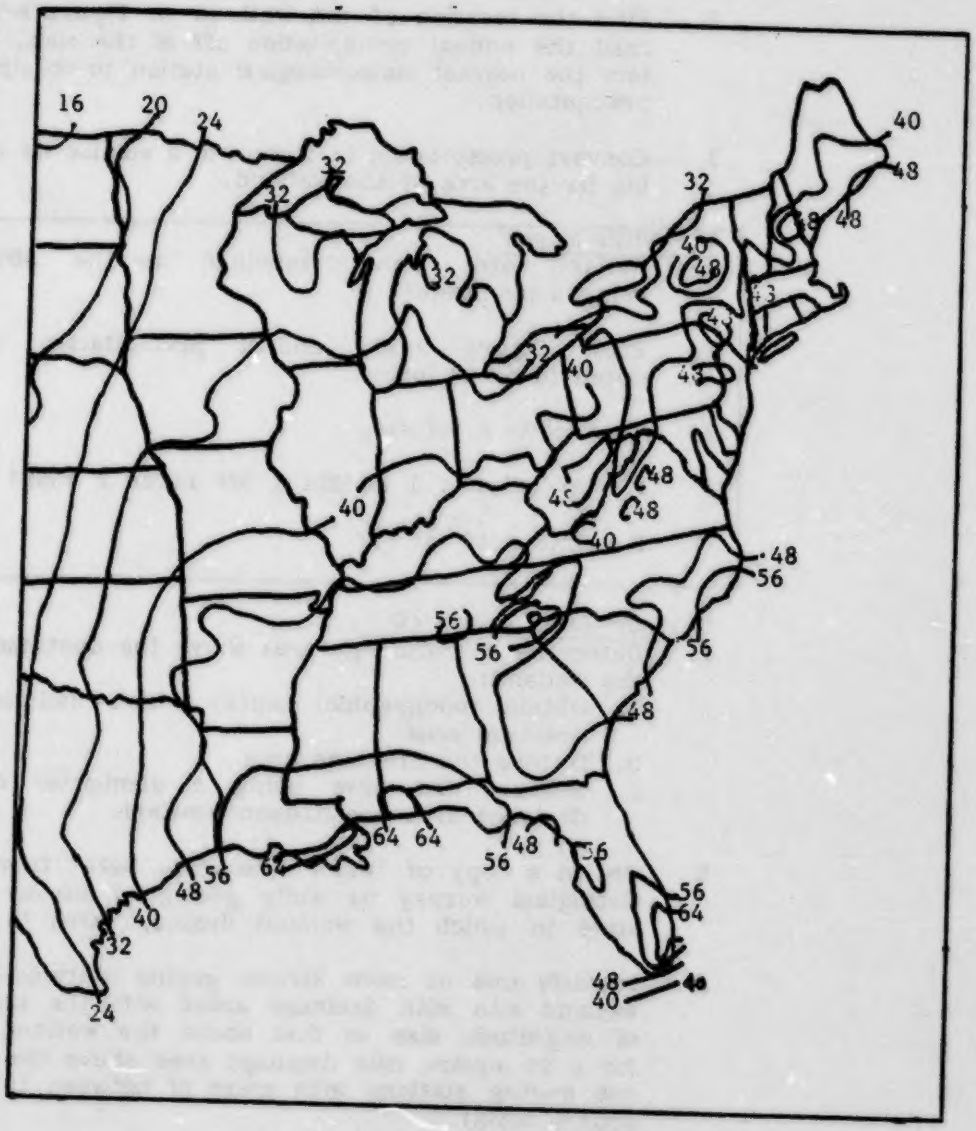
1. Determine the drainage area above the upstream end of the wetland:
   - a. Obtain topographic map(s) which include(s) the drainage area
   - b. Outline the drainage area
   - c. Measure the area using a planimeter or other drainage area measurement method.

2. Obtain a copy of "Water Resources Data" from the US Geological Survey or state geological survey for the state in which the wetland drainage area is located.

3. Identify one or more stream gaging stations near the wetland site with drainage areas with the same order of magnitude size as that above the wetland, (e.g., for a 50 square mile drainage area above the wetland, use gaging stations with areas of between 10 and 100 square miles).

4. Tabulate the measured streamflow per unit drainage area for the stations identified in step 3. Determine an average streamflow per unit area.

Figure 9-10. Mean annual total precipitation in inches.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5. Multiply the average streamflow per unit area (step 4) by the drainage area above the upstream end of the wetland (step 1). The resulting value is an estimate of the average annual inflow rate to the wetland.

6. Convert to an annual volume of water.

For Bill's Marsh

1. Drainage area above the inflow to the wetland was determined to be 50 mi^2 using a planimeter.

2-4. The average streamflow per unit area was estimated to be 1.5 ft^3/sec/mi^2.

5. Estimate average annual inflow:

$$Q_1 = 1.5 \text{ ft}^3/\text{sec}/\text{mi}^2 \times 50 \text{ mi}^2 = 75 \text{ ft}^3/\text{sec}$$

6. Convert to a volume:

$$Q_1 = 75 \text{ ft}^3/\text{sec} \times 86400 \text{ sec/day} \times 365 \text{ days/yr}$$

$$Q_1 = 2{,}365 \times 10^6 \text{ ft}^3/\text{yr}$$

Lateral Overland Flow (Q_L).

1. Determine the drainage area contributing directly to the wetland:
   - a. Use the topographic map(s) described for the surface water inflow determination
   - b. Outline the drainage area contributing directly to the wetland
   - c. Measure the area using a planimeter or other area measurement method.

2. Multiply the average streamflow per unit area (step 4 of the surface water inflow determination) by the drainage area directly contributing to the wetland.

3. Convert this to an annual volume of water.

For Bill's Marsh

1. The drainage area contributing directly to the wetland was determined to be 1 mi^2 using a planimeter.

2. Estimate average annual inflow:

$$Q_L = 1.5 \text{ ft}^3/\text{sec}/\text{mi}^2 \times 1 \text{ mi}^2 = 1.5 \text{ ft}^3/\text{sec}$$

3. Convert to a volume:

$$Q_L = 1.5 \text{ ft}^3/\text{sec} \times 86400 \text{ sec/day} \times 365 \text{ days/yr}$$

$$Q_L = 47.3 \times 10^6 \text{ ft}^3/\text{yr}$$

Groundwater Inflow or Outflow (G_1 or G_2).

1. Obtain soil survey and geological reports for the county in which the wetland is located. Soil surveys are obtained from the US Department of Agriculture Soil Conservation Service office in the county where the wetland is located. Geological reports may be obtained from the state geological survey.

2. List the soils and geology underlying the wetland. For each soil, list its permeability or drainage characteristics (poorly drained, moderately drained, well drained). Look for evidence of confining soil or rock layers under the wetland.
   a. If a confining layer exists or is indicated, assume $G_1 = G_2 = 0$.
   b. If a confining layer does not exist or is not indicated, the analyst should be cautious about using this method since seepage losses may be significant. In applying this method, assume $G_1 = G_2 = 0$.
   c. If no information is available, assume $G_1 = G_2 = 0$.

For Bill's Marsh

A confining layer of clay is indicated.

Assume $G_1 = G_2 = 0$.

Wastewater Application (W).

1. Wastewater application rate is normally zero for existing conditions unless wastewater is currently being applied and the evaluation is to be made for additional wastewater application.

2. Wastewater application rate must be specified for evaluation of hydrologic change due to a wastewater application. Generally, this will be presented in units of million gallons per day (MGD).

3. Convert this to an annual volume by multiplying by 365 days (or the number of days the wastewater is to be applied). The resulting volume will be in millions of gallons.

For Bill's Marsh

Under baseline (existing) conditions W = O

Evapotranspiration (E).

1. Find the location of the wetland in Figure 9-11, and read the annual pan evaporation off of the map.

2. Determine shallow lake evaporation by multiplying the pan evaporation by 0.7. Use shallow lake evaporation as an estimate of evapotranspiration. Note that the method does not consider variations in evapotranspiration as a result of vegetation changes.

3. Convert to a volume by multiplying by the wetland area.

For Bill's Marsh

1. From Figure 9-11, average annual pan evaporation is estimated to be 55 inches.

2. Determine shallow lake evaporation:

   $E = 55 \text{ inches} \times 0.7 = 38.5 \text{ inches}$

3. Convert to a volume:

   $E = 38.5 \text{ in/yr} \times 1\text{ft}/12\text{in} \times 300 \text{ acres} \times 43560 \text{ ft}^2/\text{acre}$

   $E = 41.9 \times 10^6 \text{ ft}^3/\text{yr}$

Surface Water Outflow (Q_2).

1. Estimate total annual volume by solving the annual water budget equation for Q_2.

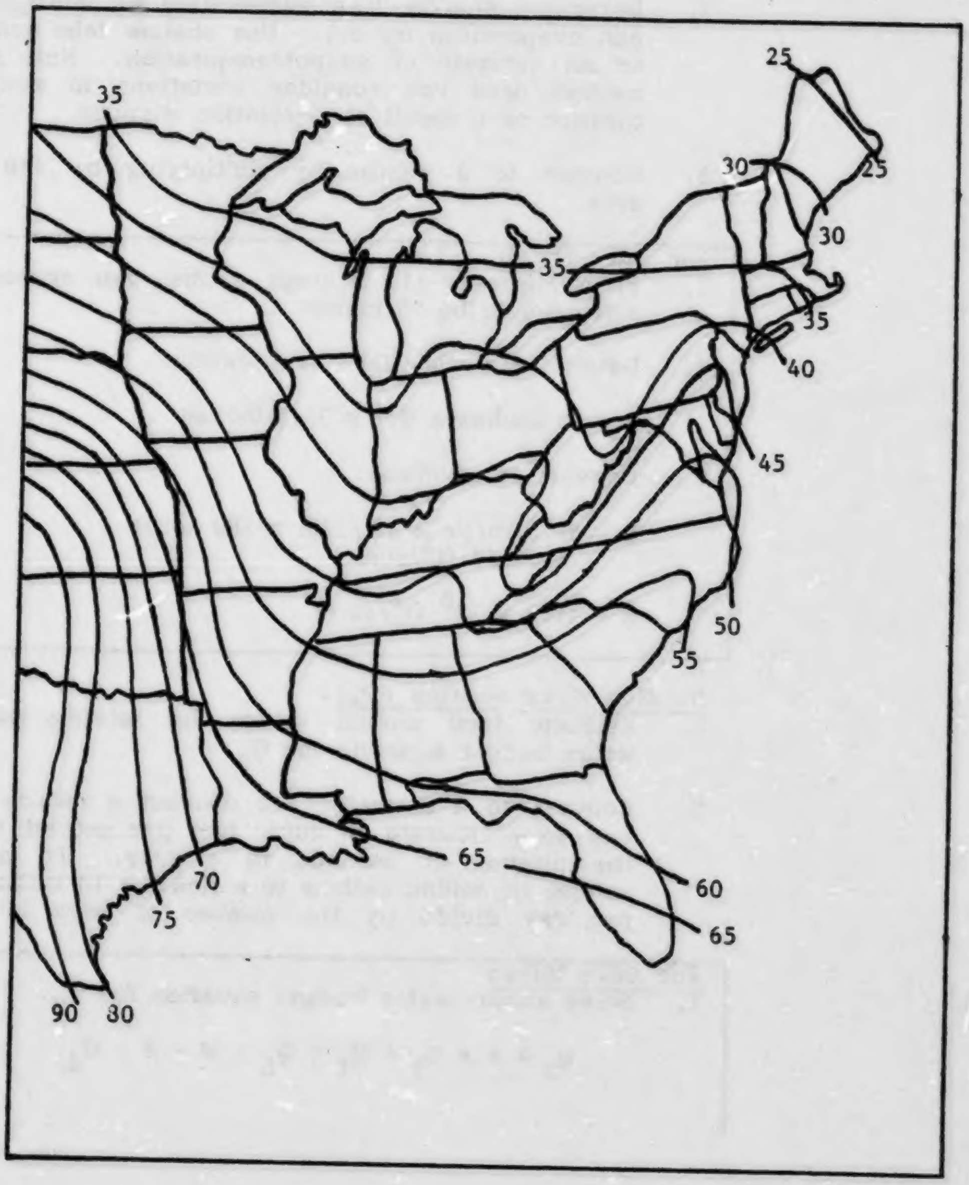
2. Convert to a flowrate. To convert a volume in cubic feet to a flowrate in cubic feet per second divide by the number of seconds in a year. To convert a volume in million gallons to a flowrate in million gallons per day divide by the number of days in a year.

For Bill's Marsh

1. Solve annual water budget equation for Q_2:

$$Q_2 = P + G_1 + Q_1 + Q_L + W - E - G_2$$

Figure 9-11. Mean annual pan evaporation in inches.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$$\begin{aligned} Q_2 = \; & 52.3 \times 10^6 \\ & + 0.0 \\ & + 2365 \times 10^6 \\ & + 47.3 \times 10^6 \\ & + 0.0 \\ & - 41.9 \times 10^6 \\ & - 0.0 \\ \hline Q_2 = \; & 2{,}423 \times 10^6 \text{ ft}^3/\text{yr} \end{aligned}$$

2. Convert to a flowrate:

$$Q_2 = 2423 \times 10^6 \text{ ft}^3/\text{yr} \times 1 \text{ yr}/365 \text{ days} \times 1 \text{ day}/86400 \text{ sec}$$

$$Q_2 = 76.8 \text{ ft}^3/\text{sec}$$

Steps 5-11 include the procedure for performing the Manning's equation analysis for hydrologically open wetland systems without an identifiable channel, such as in the illustration for Bill's Marsh.

The objective of the analysis is to predict the depth of flow in the wetland using Manning's equation. This objective can only be met when the following information is known:

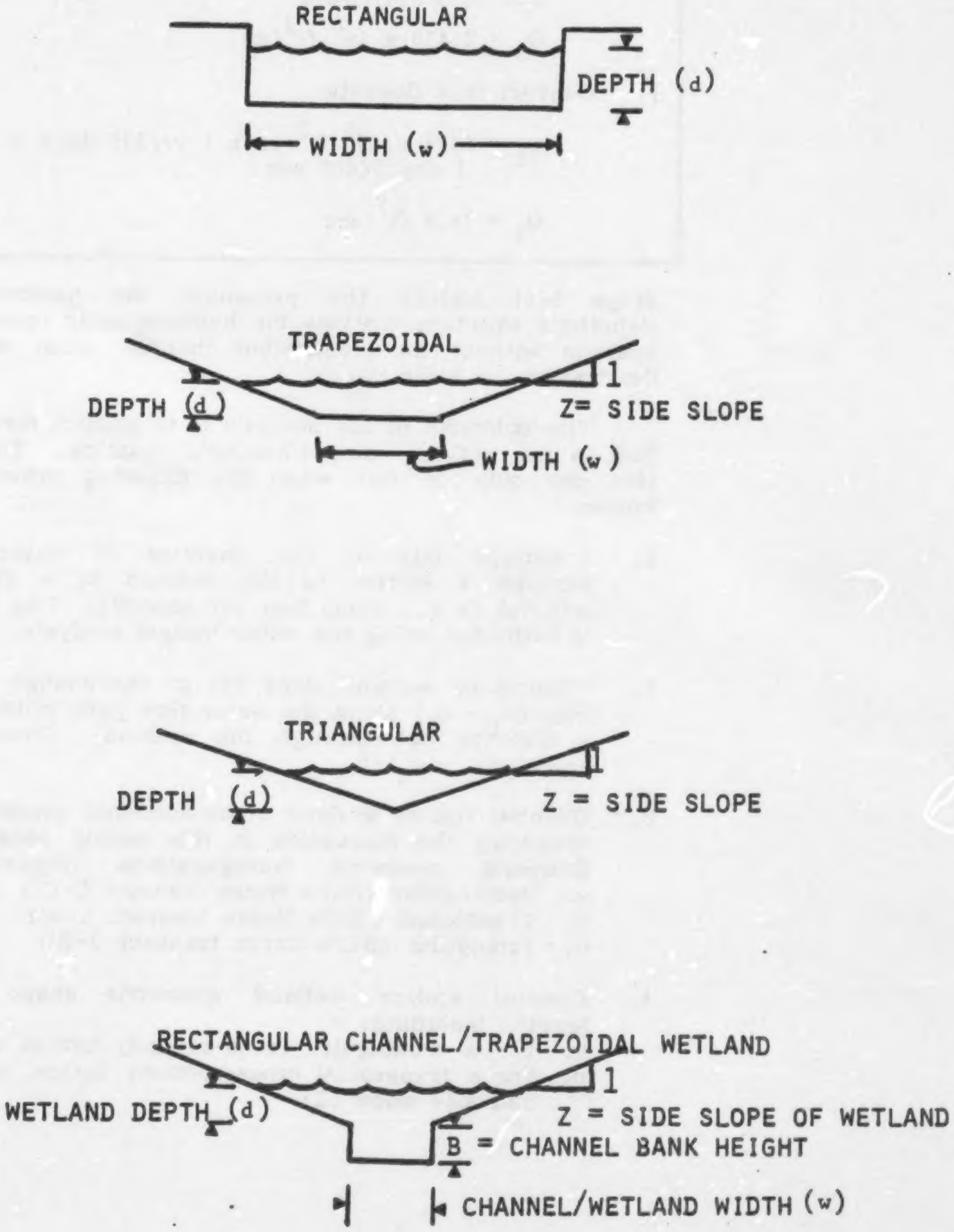
1. Discharge (Q) or the quantity of water flowing through a section of the wetland in a given time interval (e.g., cubic feet per second). The discharge is estimated using the water budget analysis.

2. Channel or wetland slope (S) or the change in elevation ($e_1 - e_2$) along the water flow path which extends a distance (L) through the wetland. Channel slope equals $(e_1 - e_2)/L$.

3. Channel and/or wetland cross-sectional geometry. For simplicity the discussion in this secton considers the following geometric configurations (Figure 9-12):
   a. Rectangular (Bill's Marsh transect C-C')
   b. Trapezoidal (Bill's Marsh transect A-A')
   c. Triangular (Bill's Marsh transect B-B')

4. Channel and/or wetland geometric shape defining lengths including:
   a. For a rectangular cross-section; bottom width (w)
   b. For a trapezoidal cross-section; bottom width (w), and side slope (Z)

Figure 9-12. Wetland/channel geometric shapes with defining lengths.


RECTANGULAR
DEPTH (d)
WIDTH (w)
TRAPEZOIDAL
1
DEPTH (d)
Z= SIDE SLOPE
WIDTH (w)
TRIANGULAR
1
DEPTH (d)
Z = SIDE SLOPE
RECTANGULAR CHANNEL/TRAPEZOIDAL WETLAND
1
WETLAND DEPTH (d)
Z = SIDE SLOPE OF WETLAND
B = CHANNEL BANK HEIGHT
CHANNEL/WETLAND WIDTH (w)

c. For a triangular cross-section; side slope (Z) Figure 9-12 shows each of these geometric shapes and illustrates bottom width (w), side slope (Z), and depth (d) for each of these shapes.

5. If a well-defined channel is present, the bank height (B); that is, the depth at which flow in the channel spills over onto the adjacent wetland floodplain (see Figure 9-12).

6. Mannning's roughness coefficient (n). The roughness coefficient is determined on the basis of best engineering judgement and depends on the surface roughness of the channel or wetland resisting the flow, vegetation, channel or wetland irregularities (holes and humps), channel or wetland curvature, silting and scouring, obstructions (jams, bridge piers), and stage and discharge (Chow 1959). For more detail on the determination of Manning's-n including pictures illustrating a variety of n-values, the user of this manual should consult Chow (1959) or Arcement and Schneider (1984). A list of representative values of n for wetlands is provided in Table 9-26.

When all of these factors are known, Manning's equation can be solved for depth of flow. For simplicity, Manning's equation is rewritten as:

$$(1.49)^{-1} Q\ n\ S^{-1/2} = A^{5/3}\ P^{-2/3}$$

For known or specified values of Q, n, and S, the left-hand side of this equation is a constant (C):

$$C = A^{5/3}\ P^{-2/3}$$

Cross-sectional area (A) and wetted perimeter (P) are determined by the depth of flow and the cross-sectional geometry. For known values of width (rectangular and trapeziodal cross-sections) and side slope (trapezoidal and triangular cross-sections), depths of flow may be estimated by trial and error or from Figure 9-13 for (trapezoidal and rectangular) cross-sections or explicitly for triangular cross-sections.

Step 5 - Select Cross-Sections A minimum of two cross-sections should be selected for Manning's equation analysis. The first should be near the upstream end of the wetland; the second should be near the downstream end of the wetland. Additional cross-sections should be selected at the anticipated location of the wastewater discharge and at locations where the wetland geometry or Manning's-n changes or where there is a structural control of flow.

Table 9-26. Factors that effect roughness of the channel.

Flood plain conditions		n value adjustment	Example
Degree of irregularity (n_1)	Smooth	0.000	Compares to the smoothest, flattest flood plain attainable in a given bed material.
	Minor	0.001-0.005	Is a flood plain with minor irregularity in shape. A few rises and dips or sloughs may be visible on the flood plain.
	Moderate	0.006-0.010	Has more rises and dips. Sloughs and hummocks may occur.
	Severe	0.011-0.020	The flood plain is very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pastureland and furrows perpendicular to the flow are also included.
Variation of flood-plain cross section (n_2)		0.0	Not applicable.
Effect of obstructions (n_3)	Negligible	0.000-0.004	A few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, or isolated boulders, occupy less than 5 percent of the cross-sectional area.
	Minor	0.005-0.019	Obstructions occupy less than 15 percent of the cross-sectional area.
	Appreciable	0.020-0.030	Obstructions occupy from 15 to 50 percent of the cross-sectional area.

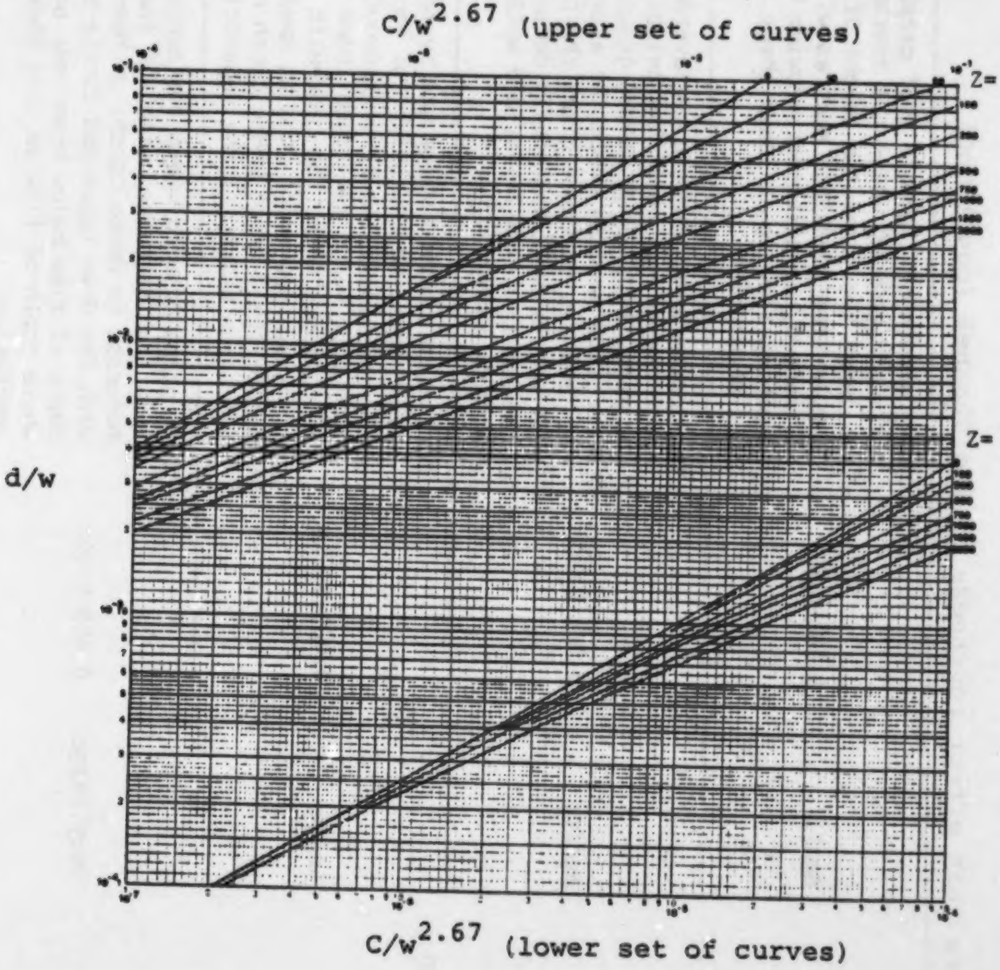
Table 9-26. Factors that effect roughness of the channel (concluded).

Amount of vegetation (n_4)	Small	0.001-0.010	Dense growth of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; or supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	0.011-0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation; or moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season.
	Large	0.025-0.050	Turf grass growing where the average depth of flow is about equal to the height of vegetation; or 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 ft; or mature row crops such as small vegetables; or mature field crops where depth of flow is at least twice the height of the vegetation.
	Very large	0.050-0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation; or moderate to dense brush; or heavy stand of timber with few down trees and little undergrowth with depth of flow below branches; or mature field crops where depth of flow is less than height of the vegetation.
	Extreme	0.100-0.200	Dense bushy willow, mesquite, and saltcedar (all vegetation in full foliage); or heavy stand of timber, few down trees, depth of flow reaching branches.
Degree of meander (m)		1.0	Not applicable.

Calculate Manning's-n as follows: $n = m\ (n_1 + n_2 + n_3 + n_4)$

Source: Arcement and Schneider 1984.

Figure 9-13. Nomograph for determining depth of flow for rectangular and trapezoidal cross-sections.



For Bill's Marsh

Three cross-sections were selected for Manning's equation analysis. These cross-sections (Figure 9-9) include the following:

1. Section A-A' is located near the upstream end of Bill's Marsh where streamflow is approximately 75 ft^3/sec. The cross-section is closest to a trapezoidal shape.
2. Section B-B' is located near the middle of the wetland where streamflow is approximately 76 ft^3/sec. The cross-section is closest to a triangular shape.
3. Section C-C' is located near the downstream end of Bill's Marsh where streamflow is approximately 77 ft^3/sec. The cross-section is closest to a rectangular shape.

Step 6 - Is There A Channel? Steps 7 through 12 are completed for each cross-section. If there is a structural control of flow, this cross-section should be analyzed first. If there is a single, well-defined channel in the wetland, skip to Step 17.

For Bill's Marsh

There is no structural control of flow; therefore cross-sections will be evaluated from upstream end to downstream end of the wetland. There is no single, well-defined channel in the wetland; therefore complete steps 7-12 for each cross-section.

Step 7 - Wetland Geometry and Manning's-n. Determine whether the wetland cross-section geometry is triangular, trapezoidal, or rectangular (see Figure 9-12). Estimate side slope (Z) for triangular and trapezoidal sections, and bottom width (w) for rectangular and trapezoidal sections. Estimate Manning's-n from information collected on the site survey, from Table 9-26, or by using a default value of n = 0.25. Enter this information on the cross-section diagram developed in Step 3.

For Bill's Marsh

First Section: Section A-A' is trapezoidal with side slope (Z) equal to horizontal distance divided by vertical distance:

$$Z = 900 \text{ ft}/1 \text{ ft} = 900$$

Bottom width (w) = 400 ft

Manning's-n(n) is estimated from Table 9-26:

$n_1 = 0.010$ $n_3 = 0.02$

$n_2 = 0.0$ $n_4 = 0.17$

$m = 1.0$

$$n = m(n_1 + n_2 + n_3 + n_4) = 0.20$$

Enter values for Z, w, and n on cross-section diagram (Figure 9-9).

Second Section: Section B-B' is a triangular with side slope (z) equal to horizontal distance divided by vertical distance:

$$Z = 1300 \text{ ft}/1 \text{ ft} = 1300$$

Manning's-n (n) is estimated from Table 9-26:

$n_1 = 0.01$ $n_3 = 0.02$

$n_2 = 0.0$ $n_4 = 0.12$

$m = 1.0$

$$n = m(n_1 + n_2 + n_3 + n_4) = 0.15$$

Enter values for Z and n on cross-section diagram (Figure 9-9).

Third Section: Section C-C' is rectangular with side slope (Z) equal to zero and bottom width equal to 2100 ft:

$Z = 0$

$w = 2100$ ft

Manning's-n (n) is estimated from Table 9-26:

$n_1 = 0.02$ $n_3 = 0.03$

$n_2 = 0.0$ $n_4 = 0.20$

$m = 1.0$

$$n = m\,(n_1 + n_2 + n_3 + n_4) = 0.25$$

Enter values for Z, w, and n on cross-section diagrams (Figure 9-9).

Step 8 - Determine Flow Depth (No Structural Control). If there is a structural control, go to Step 9; otherwise determine the flow depth explicitly for a triangular section or by trial and error or using the nomograph in Figure 9-13 for rectangular and trapezoidal sections.

Rectangular Cross-sections. For rectangular cross-sections:

$$C = A^{5/3}\ P^{-2/3} = (wd)^{5/3}\ (w + 2d)^{-2/3}$$

When values of Q, n, S, and w are known, the depth of flow (d) can be determined by trial and error as follows:

1. Estimate Q, n, S, and w.
2. Calculate $C = (1.49)^{-1}\ Q\ n\ S^{-0.5}$.
3. Insert the value of w into the right-hand side of the equation above and make an initial guess at flow depth (d').
4. Calculate $C' = (wd')^{1.67}\ (w + 2d')^{-0.67}$.

5a. If C' is very close to C, use the most recent depth (d') as the estimate of the flow depth (d).

5b. If C' is greater than C, try another depth (d') which is smaller than the previous d'. Return to step 4.

5c. If C' is less than C, try another depth (d') which is greater than the previous d'. Return to step 4.

For Bill's Marsh - Section C-C'

1. Estimate Q, n, s, and w.

$$Q = 77\ ft^3/sec$$
$$n = 0.25$$
$$S = 0.0003$$
$$w = 2100\ ft$$

2. Calculate $C = (1.49)^{-1}\ Q\ n\ S^{-0.5}$

$$C = (0.67)\ (77)\ (0.25)\ (0.0003)^{-0.5}$$
$$C = 746$$

3. Assume d' = 0.8 ft

4. Calculate $C' = (wd')^{1.67}\ (w + 2d')^{-0.67}$

$$C' = (2100 \times 0.8)^{1.67}\ (2100 + 2 \times 0.8)^{-0.67}$$
$$C' = (1680)^{1.67}\ (2102)^{-0.67}$$
$$C' = (243{,}370)\ (0.006)$$
$$C' = 1446$$

5b. C' is greater than C, try d' = 0.6 ft.

4. Calculate $C' = (wd')^{1.67} (w + 2d')^{-0.67}$

$$C' = (2100 \times 0.6)^{1.67} (2100 + 2 \times 0.6)^{-0.67}$$
$$C' = (150{,}529)\ (0.006)$$
$$C' = 894$$

5b. C' is greater than C, try d' = 0.54 ft.

4. Calculate $C' = (wd')^{1.67} (w + 2d')^{-0.67}$

$$C' = (2100 \times 0.54)^{1.67} (2100 + 2 \times 0.54)^{-0.67}$$
$$C' = (126{,}242)\ (0.006)$$
$$C' = 750$$

5a. C' is approximately equal to C; therefore the flow depth is estimated to be d = 0.54 ft. above the lowest elevation in the cross-section (0.2 ft.). Therefore the water surface elevation is at 0.54 ft plus 0.2 ft or 0.74 ft.

For rectangular cross-sections, if depth (d) is less than 1% of the width, the flow depth may be determined as follows:

1. Estimate Q, n, S, and w.
2. Calculate $C = Q\ n\ S^{-1/2} (1.49)^{-1}$
3. Calculate flow depth: $d = (C/w)^{0.60}$

For Bill's Marsh - Section C-C'

1. Estimate Q, n, S, and w.

$Q = 77\ \text{ft}^3/\text{sec}$
$n = 0.25$
$S = 0.0003$
$w = 2100\ \text{ft}$

2. Calculate $C = Qn\ (1.49)^{-1} S^{-0.5}$

$$C = 77\ (0.25)\ (0.67)\ (0.0003)^{-0.5}$$
$$C = 745$$

3. Calculate flow depth:

$$d = (C/w)^{0.60}$$
$$d = (745/2100)^{0.60}$$
$$d = 0.54\ \text{ft}$$

The flow depth (water surface elevation) is 0.54 ft above the lowest elevation in the cross-section (0.2 ft). Therefore, the water surface elevation is 0.74 ft (0.54 ft plus 0.2 ft).

For rectangular cross-sections, a flow depth is determined from the nomograph in Figure 9-13 as follows:

1. **Estimate Q, n, S, Z, and w.**
2. **Calculate $Cw^{-2.67} = (1.49)^{-1}\ Q\ n\ S^{-0.5}\ w^{-2.67}$**
3. **Enter the graph (Figure 9-13) at the value of $Cw^{-2.67}$ on the horizontal axis. Move vertically until the line with a value of Z = O (rectangle) is intersected. Move horizontally (to the left) until reaching the vertical axis. Read the value for d/w.**
4. **Multiply the value of d/w by the width (w) of the rectangular cross-section. The resulting value is the flow depth (d).**

For Bill's Marsh - Section C -C'

1. **Estimate Q, n, S, Z, and w.**

   $Q = 77\ \text{ft}^3/\text{sec}$

   $n = 0.25$

   $S = 0.0003$

   $Z = 0$

   $w = 2100\ \text{ft}$

2. **Calculate $Cw^{-2.67} = Q\ n\ (1.49)^{-1} S^{-0.5} w^{-2.67}$**

   $$Cw^{-2.67} = (77)\ (0.25)\ (1.49)^{-1}\ (0.0003)^{-0.5} (2100)^{-2.67}$$

   $$Cw^{-2.67} = (77)\ (0.25)\ (0.67)\ (57.7)\ (1.35 \times 10^{-9})$$

   $$Cw^{-2.67} = 1.00 \times 10^{-6}$$

3. **Enter the graph (Figure 9-13) at 1.00×10^{-6} on the horizontal axis. Move vertically to the Z = 0 line. Move horizontally (to the left) to the vertical axis. Read the value for d/w.**

   $$d/w = 2.57 \times 10^{-4}$$

4. **Calculate: $d = (2.57 \times 10^{-4})\ w$**

   $$d = (2.57 \times 10^{-4})\ (2100)$$

   $$d = 0.54\ \text{ft}$$

The flow depth (water surface elevation) is 0.54 ft above the lowest elevation in the cross-section (0.2 ft). Therefore, the water surface elevation is 0.74 ft (0.54 ft plus 0.2 ft).

Trapezoidal Cross-sections. For trapezoidal cross-sections:

$$C = A^{5/3}P^{-2/3} = d^{5/3} (w+Zd)^{5/3} [2d(1+Z^2)^{1/2}+w]^{-2/3}$$

When values of Q, n, S, Z and w are known, the depth of flow (d) can be determined by trial and error as follows:

1. Estimate Q, n, S, Z and w.
2. Calculate $C = (1.49)^{-1} Q\, n\, S^{-0.5}$.
3. Insert the values of w and Z into the righthand side of the equation above and make an initial guess at flow depth (d').
4. Calculate: $C' = (d')^{1.67} (w + Zd')^{1.67} [2d'(1 + Z^2)^{0.5} + w]^{-0.67}$

5a. If C' is very close to C, use the most recent depth (d') as the estimate of the flow depth (d).
5b. If C' is greater than C, try another depth (d') which is smaller than the previous d'. Return to step 4.
5c. If C' is less than C, try another depth (d') which is greater than the previous d'. Return to step 4.

For Bill's Marsh - Section A-A'

The trial-and-error solution is completed in the same way shown for the rectangular cross-section (Section C-C'). Therefore, the trial-and-error solution method is not illustrated for Section A-A'.

Flow depth is determined from the nomograph in Figure 9-13 as follows:

1. Estimate Q, n, S, Z and w.
2. Calculate $Cw^{-2.67} = (1.49)^{-1} Q\, n\, S^{-0.5}\, w^{-2.67}$
3. Enter the graph (Figure 9-13) at the value of $Cw^{-2.67}$ on the horizontal axis. Move vertically until the line with a Z-value closest to the observed side slope is intersected. Move horizontally (to the left) until reaching the vertical axis. Read the value for d/w.
4. Multiply the value of d/w by the bottom width (w) of the trapezoidal cross-section. The resulting value is the flow depth (d).

For Bill's Marsh - Section A-A'

1. Estimate Q, n, W, Z, and w.

$Q = 75\ \text{ft}^3/\text{sec}$
$n = 0.20$
$S = 0.0003$
$Z = 900$
$w = 400\ \text{ft}$

2. Calculate $Cw^{-2.67} = Qn\ (1.49)^{-1} S^{-0.5} w^{-2.67}$

$$Cw^{-2.67} = (75)\ (0.20)\ (1.49)^{-1}\ (0.0003)^{-0.5}\ (400)^{-2.67}$$

$$Cw^{-2.67} = (75)\ (0.20)\ (0.67)\ (57.7)\ (1.13 \times 10^{-7})$$

$$Cw^{-2.67} = 6.55 \times 10^{-5}$$

3. Enter graph (Figure 9-13) at 6.55×10^{-5} on the horizontal axis. Move vertically to the approximate location of the Z = 900 line. Move horizontally (to the left) to the vertical axis. Read the value for d/w.

$$d/w = 2.1 \times 10^{-3}$$

4. Calculate: $d = (2.1 \times 10^{-3})\ w$
$d = (2.1 \times 10^{-3})\ (400)$
$d = 0.84\ \text{ft}$

The flow depth (water surface elevation) is 0.84 ft above the lowest elevation in the cross-section (0.8 ft). Therefore, the water surface elevation is 1.64 ft (0.84 plus 0.8 ft).

Triangular Cross-sections. For triangular cross-sections, flow depth is determined as follows:

1. Estimate Q, n, S, and Z
2. Calculate $C = Q\ n\ S^{-1/2}\ (1.49)^{-1}$
3. Calculate flow depth:

$$d = C^{0.375}\ \left[\ (Z^2 + 1) Z^{-5}\ \right]^{0.125}$$

For Bill's Marsh - Section B-B'

1. Estimate Q, n, S, and Z.

$Q = 76\ \text{ft}^3/\text{sec}$
$n = 0.15$
$S = 0.0003$
$Z = 1300$

2. Calculate $C = Qn\ (1.49)^{-1} S^{-0.5}$

$$C = (76)\ (0.15)\ (1.49)^{-1}\ (0.0003)^{-0.5}$$
$$C = (76)\ (0.15)\ (0.67)\ (57.7)$$
$$C = 441$$

3. Calculate flow depth:

$$d = C^{0.375}\ [(Z^2 + 1)\ Z^{-5}]^{0.125}$$
$$= (441)^{0.375}\ [\ (1300^2 + 1)\ 1300^{-5}\ ]^{0.125}$$
$$= (411)^{0.375}\ (4.55 \times 10^{-10})^{0.125}$$
$$= (9.81)\ (.068)$$
$$= 0.67 \text{ ft}$$

The flow depth (water surface elevation) is 0.67 ft above the lowest elevation in the cross-section (0.5 ft). Therefore, the water surface elevation is 1.17 ft (0.67 ft plus 0.5 ft).

Step 9 - Determine Flow Depth (Structural Control). Determine the flow depth for an open hydrologic system with a structural control. Depth will vary depending on the type of control. For controls such as fills and bridge pier contractions, use Manning's equation with the following data inputs:

a. Slope (S) is the slope of the ground surface in the vicinity of the control.

b. Manning's-n(n) is the roughness coefficient of the ground surface in the vicinity of the control.

c. Flow (Q) is as previously determined for the cross-section.

The structural control's cross-sectional geometry then dictates the depth of flow. Estimate the flow depth as directed in Step 8.

The total depth of flow at the location of the cross-section is the distance from the wetland ground surface plus the depth of flow in the control.

For controls such as culverts or wiers, use the discharge equation appropriate to the type of control as indicated below (Grant 1978):

a. V-Notch (triangular) weirs:

$$Q = Kd^{2.5}$$

where: Q = discharge in ft^3/sec
d = head (depth of flow) above the bottom of the weir opening in feet
K = a constant which depends on the angle of the notch opening as follows

Angle of Notch Opening	Value of K
90	2.5
60	1.443
45	1.035
30	0.676
22½	0.497

b. Rectangular weir with end contractions:

$$Q = 3.33\ (L - 0.2d)\ d^{1.5}$$

c. Rectangular weir without end contractions and trapezoidal weir with sides slopes of 4 vertical to 1 horizontal:

$$Q = 3.367\ L\ d^{1.5}$$

where, Q = discharge in ft^3/sec
L = bottom width of weir in ft
d = depth of flow in weir in ft

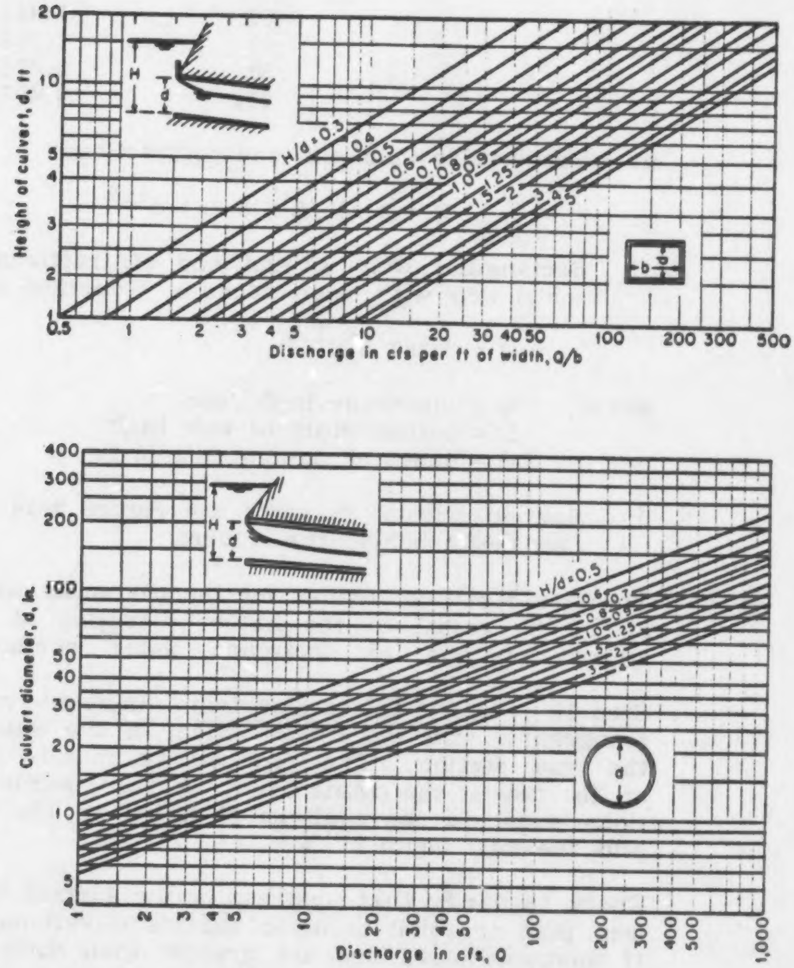
d. Box or circular culverts use Figure 9-14 to determine flow depth behind the culvert.

The flow depth determined for the particular weir or culvert should be added to the bottom elevation of the weir or culvert opening to determine water surface elevation.

Step 10 - Water Surface Elevation. Indicate on the detailed topographic map the lateral extent of the water surface at the cross-section. This can best be done by putting a dot on the map at the points along the cross-section with elevations equal to the minimum elevation on the cross-section plus the total depth of flow.

Check to verify that upstream water surface elevations are less than or equal to water surface elevations downstream. If upstream elevations are greater than downstream elevations, adjust the water surface elevations so that upstream and downstream water surface elevations are the same. Assume this elevation is equal to the average of the originally estimated water surface elevations.

Figure 9-14. Charts for estimating headwater on box culverts and circular culverts.



Source: Chow 1959.

For Bill's Marsh

Water surface elevations were determined in Step 8 for the three cross-sections in Bill's Marsh as follows:

Section	Elevation (ft)
A-A'	1.64
B-B'	1.17
C-C'	0.74

Place dots on Figure 9-7 on the Section A-A' line at the 1.64 ft elevations.
Place dots on Figure 9-7 on the Section B-B' line at the 1.17 ft elevations.
Place dots on Figure 9-7 on the Section C-C' line at the 0.74 ft elevations.

Step 11 - Cross-Sectional Area and Velocity. Calculate the cross-sectional area (A) of flow in the cross-section as follows:

a. For a rectangle, $A = (wd)$.
b. For a trapezoid, $A = (w + Zd)d$.
c. For a triangle, $A = Zd^2$.

Calculate velocity $(V) = Q/A$. For each cross-section, enter flow (Q), velocity (V), cross-sectional area (A), and depth(d) on Form 9-A.

For Bill's Marsh

a. Section C-C' is rectangular:

$A = (wd) = 2100 \text{ ft}) (0.54 \text{ ft})$
$A = 1134 \text{ ft}^2$

Velocity $(V) = Q/A = 77 \text{ ft}^3/\text{sec}/1134 \text{ ft}^2$
$V = 0.068 \text{ ft/sec}$

Enter these values on Form 9-A (Table 9-27).

b. Section A-A' is trapezoidal:

$A = (w + Zd)\ d = (400 + 900 \times 0.84)\ (0.84)$
$A = 971 \text{ ft}^2$

Velocity $(V) = Q/A = 75 \text{ ft}^3/\text{sec}/971 \text{ ft}^2$
$V = 0.077 \text{ ft/sec}$

Enter these values on Form 9-A (Table 9-27).

c. Section B-B' is triangular:

$$A = Zd^2 = {}_2(1300 \text{ ft})\ (0.67 \text{ ft})^2$$
$$A = 584 \text{ ft}^2$$

$$\text{Velocity } (V) = Q/A = 76 \text{ ft}^3/\text{sec}/584 \text{ ft}^2$$
$$V = 0.130 \text{ ft/sec}$$

Enter these values on Form 9-A (Table 9-27).

Step 12 - Additional Cross-Sections? If there is another cross-section to evaluate, return to Step 6. If there are no more cross-sections, proceed to Step 13.

Step 13 - Area of-Inundation and Residence Time. After all cross-sections have been evaluated to determine depths of flow, cross-sectional area, and velocity and after the extent of the water surface has been plotted on the detailed topographic map, outline the area covered by the water surface on the topographic map. Use a planimeter to determine the area-of-inundation. Calculate the average flow depth and average velocity for the cross-sections evaluated. Calculate residence time (T) = wetland flow length (L)/average velocity (V). Enter these values on Form 9-A.

For Bill's Marsh

In Figure 9-7, connect the dots on each side of the wetland to show the lateral extent of the water surface. This is the outlined area-of-inundation. The area was measured with a planimeter and found to be 230 acres.

The average flow depth, velocity, and cross-sectional areas are determined in Table 9-27 by adding values in each column and dividing by 3.

Calculate the residence time (T):

$$T = L/V$$
$$T = 3600 \text{ ft}/0.092 \text{ ft/sec}$$
$$T = 39{,}130 \text{ sec} = 10.9 \text{ hours}$$

Residence time is entered on Form 9-A (Table 9-27).

Steps 14 and 15 are completed to develop a water budget for the wetland with the wastewater application. The water budget is used to estimate flows in the wetland with the wastewater application. Once the flows have been determined the analysis returns to step 6 for the Manning's equation analysis. The analysis is completed exactly as was done for existing conditions except new flows are used. Results of the analysis are tabulated on Form 9-A.

Step 14 - Analysis for Wastewater Application. Proceed to Step 15 for the analysis of flow characteristics for the situation in which wastewater is applied to the wetland. If this analysis has been completed, go to Step 16.

For Bill's Marsh

Detailed calculations are provided for the water budget analysis only (Step 15). The details of the Manning's-n equation analysis are not provided for Bill's Marsh with the wastewater application. However, the results of the analysis are tabulated on Form 9-A (Table 9-27). This table is then used to complete the hydraulic and hydrologic change analysis.

Step 15 - Water Budget Analysis-(Wastewater Application). Compute an annual water budget under conditions expected when wastewater is applied to the wetland. Unless there is a basis for adjusting groundwater flows (in or out), evapotranspiration, or precipitation, assume that flows in the wetland and at its downstream end will be increased by the amount of wastewater applied to the wetland. Proceed with the Manning's equation analysis by returning to Step 6.

For Bill's Marsh - Water Budget Analysis with Application

Solve the water budget equation for Q_2:

$$Q_2 = P + Q_1 + Q_L + G_1 + W - E - G_2$$

Assume P, Q_1 Q_L G_1, G_2 and E are the same as for existing conditions.

The wastewater application rate (W) = 1 MGD

$$W = 1 \times 10^6 \text{ gal/day} \times 1 \text{ day/86400 sec} \times 1 \text{ ft}^3/7.48 \text{ gal}$$

$$W = 1.5 \text{ ft}^3/\text{sec or about } 2 \text{ ft}^3/\text{sec.}$$

Therefore, Q_2 is increased by 2 ft^3/sec. Assume the wastewater is applied immediately upstream from cross-section A-A'. Flows in each of the cross-sections (A-A', B-B', C-C') are increased by 2 ft^3/sec over existing conditions. These are tabulated in Table 9-27.

Step-16 - Hydraulic and Hydrologic Change Analysis. Determine the hydraulic and hydrologic changes in the wetland as the result of the wastewater application for average velocity, average depth of flow, area-of-inundation, and residence time.

a. If the hydrologic change is minimal, no additional hydrologic evaluations are needed.

b. If the hydrologic change is a moderate, either a seasonal analysis should be conducted or the quantity of wastewater to be applied should be reduced and the basic analysis should be repeated for the new flow application rate.

c. If the hydrologic change is major, the refined analysis should be conducted or the quantity of wastewater to be applied to the wetland should be reduced and a basic analysis should be repeated for the new flow application rate.

For Bill's Marsh

Hydraulic and hydrologic changes were estimated for Bill's Marsh for average velocity, average depth of flow, area-of-inundation, and residence time. These are tabulated in Table 9-27. Parameter changes are estimated by taking the value of the parameter with the application and subtracting the value of the parameter under existing conditions. Percentage changes are computed by dividing parameter changes by the value of the parameter under existing conditions and multiplying by 100.

Change in velocity = 0 ft/sec
% Change in velocity = 100 x 0/0.092 = 0%

Change in Area-of-Inundation = 0 acres
% Change in Area-of-Inundation = 100 x 0/230 = 0%

Change in Residence Time = 0 hrs
% Change in Residence Time = 100 x 0/10.9 = 0%

Steps 17-26 are completed for situations where there is a single, well-defined channel running through the wetland. This was not the case for Bill's Marsh, so no illustrations are provided for these steps.

Step 17 - Channel/wetland Geometry and Manning's-n. Determine whether the channel cross-section is triangular, trapezoidal, or rectangular. Estimate side slope (Z) for triangular and trapezoidal sections, and bottom width (w) for rectangular and trapezoidal sections. Estimate Manning's-n from information collected on the site survey, from Table 9-26, or by using a default value of n = 0.25.

Enter this information on the cross-section diagrams developed in Step 3.

Step 18 - Determine Flow Depth (No Structural Control). If there is a structural control in the channel, go to Step 19. Otherwise determine the flow depth in the channel as directed in step 8 and continue the analysis at step 20.

Step 19 - Determine Flow Depth (Structural Control). Determine the flow depth for a channel with a structural control. Depth will vary depending on the type of control. See step 9.

Step 20 - Water Surface Elevations. If the flow depth in the channel is less than the bank height of the channel, enter the flow depth on the detailed topographic map of the wetland. This is done by putting dots on the map at both sides of the channel at the cross-section location.

Step 21 - Compute Bank Height Flow. If the flow depth in the channel is greater than the bank height of the channel, calculate the flow which would result if the depth of flow were equal to the bank height (B). This flow (Q_F) is computed by Manning's equation as follows:

For a rectangular channel:

$$Q_F = 1.49\ n^{-1}\ S^{0.5}\ (wB)^{1.67}\ (w + 2B)^{-0.67}$$

For a trapezoidal channel:

$$Q_F = 1.49\ n^{-1}\ S^{0.5}\ (w + ZB)^{1.67}\ B^{1.67}$$
$$[2B(1 + Z^2)^{0.5} + w]^{-0.67}$$

For a triangular channel:

$$Q_F = 1.49(n)^{-1}\ S^{0.5}\ B^2 Z^{1.67} (1 + Z^2)^{-0.67}$$

Step 22 - Flow Overtopping Banks. Estimate the flow (Q_o) overtopping the banks as:

$$Q_o = Q - Q_F$$

Step 23 - Determine Wetland Flow Depth. Determine the additional wetland flow depth and the total flow depth (d_T) for the cross-section. Assume that the shape of the wetland is trapezoidal with a bottom width (w) equal to the width of the channel and side slope (Z) equal to the measured side slope of the wetland. Determine the wetland depth of flow as directed in step 8 for a trapezoidal section. The total flow depth (d_T) above the channel

bottom is then bank height (B) plus the depth of flow (d) in the wetland.

Step 24 - Water Surface Elevations. Indicate on the detailed topographic map the lateral extent of the water surface at the cross-section. This is done by putting dots at the locations along the cross-section with elevations equal to the elevation of the channel bottom plus the total depth of flow (d_T).

Check to verify upstream water surface elevations are less than or equal to water surface elevations downstream. If upstream elevations are greater than downstream elevations, adjust the water surface elevations so that upstream and downstream water surface elevations are the same. Assume this elevation is equal to the average of the originally estimated water surface elevations.

Step 25 - Cross-Sectional Area and Velocity. Calculate the cross-sectional area (A) of flow in the cross-section (channel plus wetland) as directed in step 11. For each cross-section, enter flow (Q), velocity (V), cross-sectional area (A), and depth (d_T) on Form 9-A.

Step 26 - Additional Cross-Sections? If there is another cross-section to evaluate, go to that cross-section and return to Step 6. If there are no more cross-sections to be evaluated, proceed to Step 13.

Step 27 - Estimate Mean Annual Areal Extent of Water Surface. From the site survey, estimate the mean annual areal extent of the water surface at each cross-section. Indicate the extent of the water surface on the detailed topographic map and on the cross-section diagrams.

For Soggy Bottom

The detailed topographic map is provided in Figure 9-8. The mean annual extent of the water surface is indicated on the map. The extent of the water surface was estimated by a wetland ecologist during the site-survey.

Step 28 - Area-of-Inundation (Existing Conditions). Determine the approximate annual average area-of-inundation using a planimeter or other area measurement method. The planimeter should trace the line drawn on the topographic map to indicate the areal extent of the water surface in the wetland. Enter the existing area-of-inundation on Form 9-A (Table 9-28).

Table 9-28. Summary of hydrologic and hydraulic analysis results (Form 9-A) for Soggy Bottom.

Cross-Section	Flow (ft^3/sec)		Depth (ft)		Area (ft^2)		Velocity (ft/sec)	
	exist	appl	exist	appl	exist	appl	exist	appl
Not completed for a hydrologically closed wetland.								
Average			0.8	1.5				

Change in depth = 0.7 ft or 88%
Change in velocity = Not Applicable
Area-of-inundation: existing = 100 acres
application = 185 acres
Change in area-of-inundation = 85%.
Residence Time: existing = Not applicable
application = Not applicable
Change in residence time = Not applicable.

For Soggy Bottom

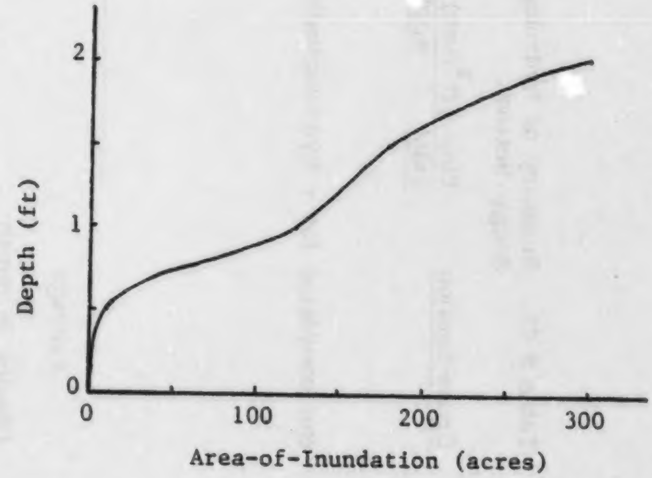
The area-of-inundation was measured using a planimeter. It was estimated to be 100 acres.

Step 29 - Graph Area-of-Inundation Versus Depth. Develop a graph showing the area-of-inundation versus the maximum depth as follows:

a. Set up a graph with area-of-inundation on the horizontal axis and maximum depth on the vertical axis.
b. Estimate the lowest elevation in the wetland.
c. Planimeter the contour enclosing an area on the topographic map.
d. Determine the maximum depth by subtracting the lowest elevation from the contour elevation.
e. Plot a point on the graph (step 29a) at the measured area-of-inundation and maximum depth.
f. If there are no more contours, go to step 29g; otherwise, go to the next contour and return to step 29c.
g. Connect the points on the graph. This graph will be used in step 32 to estimate depth with the application of wastewater.

For Soggy Bottom

a.



b. **Determine lowest elevation for the cross-sections: The lowest elevation is 0 ft.**

c and d. **Measure the area enclosed by each contour and estimate the maximum water depth if water were at the elevation of the contour. The maximum water depth is equal to the contour elevation minus the lowest elevation determined in Step 9b.**

Contour elevation (ft)	Area (acres)	Maximum Water Depth (ft)
0	0	0
0.5	10	0.5
1.0	125	1.0
1.5	180	1.5
2.0	300	2.0

e, f, and g. **Complete the graph by plotting the points and connecting them (see "a." above).**

Step 30 - Water Budget Analysis (Existing Conditions). **Compute a water budget for the closed hydrologic system under existing conditions by assuming the following:**

- a. Surface water inflow (Q_1) = 0
- b. Surface water outflow (Q_2) = 0
- c. Change in storage (ΔS) = 0

The water budget equation can be used to estimate mean groundwater flow for existing conditions:

$$G_2 - G_1 = P + Q_L - E$$

Determine the net groundwater flow per unit area-of-inundation (g) as follows:

$$g = (G_2 - G_1)/\text{area-of-inundation}$$

For Soggy Bottom

The water budget equation for a hydrologically closed system is:

$$G_2 - G_1 = P + Q_L - E$$

$P = 48\ \text{in/yr} \times 1\ \text{ft}/12\ \text{in} \times 300\ \text{acres} = 1200\ \text{acre ft/yr}$

$Q_L = 1.5\ \text{ft}^3/\text{sec/mi}^2 \times 1\ \text{mi}^2 \times 1\ \text{acre}/43560\ \text{ft}^2 \times 86400\ \text{sec/day} \times 365\ \text{day/yr} = 1086\ \text{acre ft/yr}$

$E = 55\ \text{inches/yr} \times 0.7 \times 300\ \text{acre} \times 1\ \text{ft}/12\ \text{in} = 963\ \text{acre ft/yr}$

Therefore, $G_2 - G_1 = 1200 + 1086 - 963 = 1323$ acre ft/yr

The net groundwater flow per unit area-of-inundation (g) is:

$$g = (G_2 - G_1) \text{ /area-of-inundation}$$

$$g = 1323/100 = 13.2 \text{ ft/yr}$$

Step 31 - Water Budget Analysis (Application). Compute the water budget for a closed hydrologic system with the wastewater application as follows:

a. Set up the water budget equation:

$$gA_{app} = P + Q_L - E + W$$

where: g = groundwater flow per unit area-of-inundation under existing conditions

A_{app} = total area-of-inundation with the wastewater application

P, Q_L E, and W = as previously defined

b. Solve for the new area-of-inundation (A_{app}):

$$(P + Q_L - E + W)/g = A_{app}$$

Enter the area-of-inundation with the wastewater application (A_{app}) on Form 9-A.

For Soggy Bottom

P, Q_L, and E are assumed to be the same as in Step 30.

Wastewater application rate (W) = 1 MGD

$$W = 1 \times 10^6 \text{ gal/day} \times \text{ft}^3/748 \text{ gal} \times 365 \text{ day/yr} \times \text{acre}/43560 \text{ ft}^2$$

$$W = 1120 \text{ acre-ft/yr}$$

Determine the area with the application (A_{app}):

$$A_{app} = (P + Q_L + W - E)/g$$

$$A_{app} = (1200 + 1086 + 1120 - 963)/13.2$$

$$A_{app} = 185 \text{ acres}$$

This area is entered on Form 9-A (Table 9-28).

Step 32 - Estimate New Area-of-Inundation. Enter the plot of area-of-inundation versus depth on the horizontal axis at the value determined for area-of-inundation, move vertically to the plotted line, and move horizontally to the left to the vertical axis. Read the depth value. This depth is the mean depth of the wetland. Enter this on Form 9-A and go to step 16.

For Soggy Bottom

Use the graph developed in step 29 for the Soggy Bottom illustration.

Enter the graph on the horizontal axis at 185 acres. Move vertically to the curve. Move horizontally (to the left) to the vertical axis and read the value for maximum depth. The maximum depth is 1.5 ft. Enter this on Form 9-A (Table 9-28).

Complete the hydraulic and hydrologic change analysis (step 16).

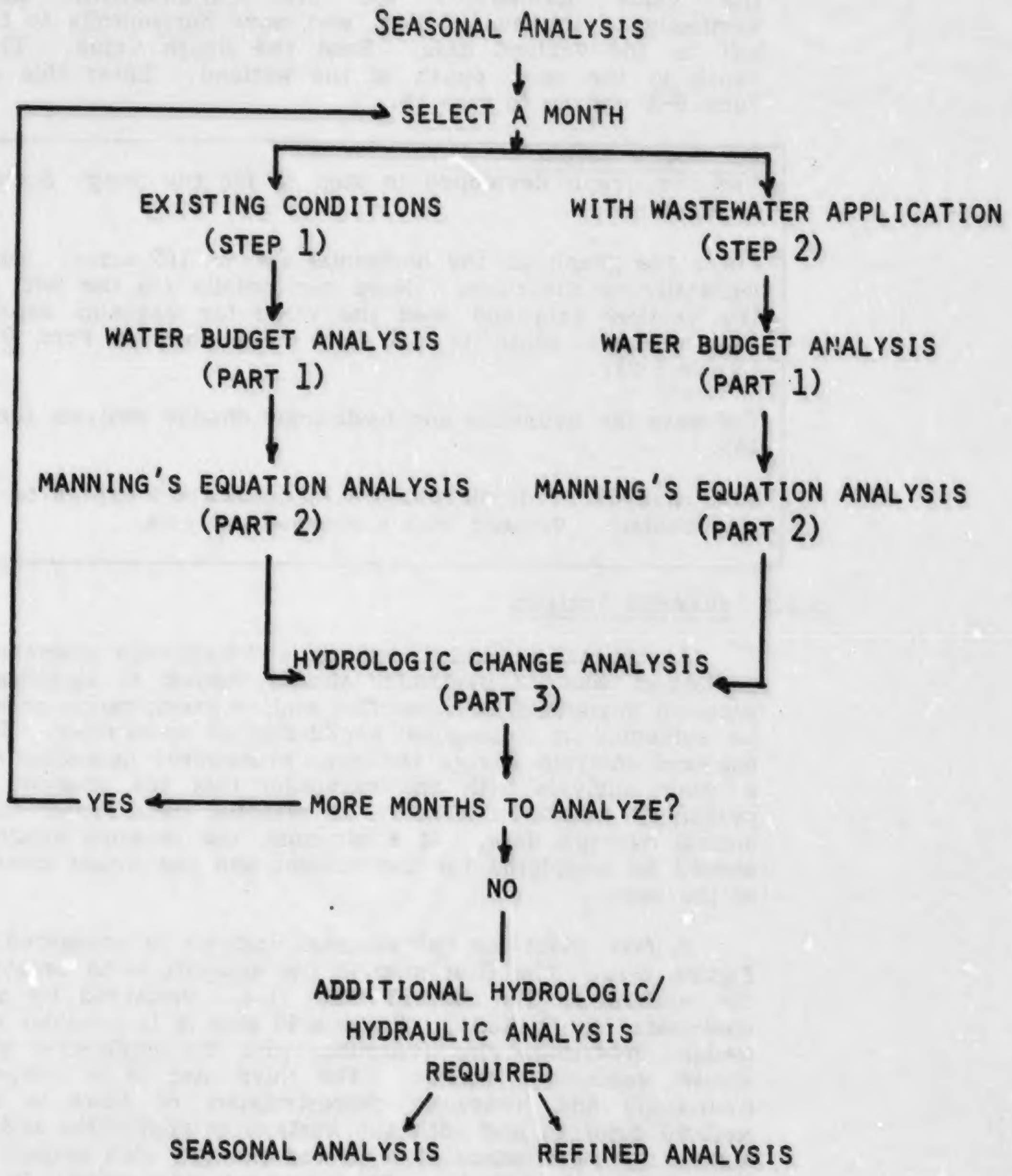
The changes in depth and area-of-inundation appear to be intermediate. Proceed with a seasonal analysis.

9.5.2 Seasonal Analysis

A seasonal wetland hydrologic and hydraulic analysis is performed when a particular site is subject to significant seasonal variations in streamflow and/or precipitation or will be subjected to a seasonal application of wastewater. The seasonal analysis follows the same procedures described for a basic analysis with the exception that the analysis is performed based on monthly or seasonal data rather than annual average data. At a minimum, the seasonal analysis should be completed for the wettest and the driest months of the year.

A flow chart for the seasonal analysis is presented in Figure 9-15. The first step in the analysis is to consider the wetland in its current state (i.e., unaltered by any wastewater application). The second step is to consider the wetland hydrology and hydraulics with the application of a known wastewater volume. The third step is to compare hydrologic and hydraulic characteristics of flows in the wetland prior to and with the wastewater application and to assess the significance of projected changes with respect to the wetland hydrology. Depending on the magnitude of change, additional refined analyses may be required.

Figure 9-15. Flow chart for a seasonal analysis.


SEASONAL ANALYSIS
SELECT A MONTH
EXISTING CONDITIONS (STEP 1)
WITH WASTEWATER APPLICATION (STEP 2)
WATER BUDGET ANALYSIS (PART 1)
WATER BUDGET ANALYSIS (PART 1)
MANNING'S EQUATION ANALYSIS (PART 2)
MANNING'S EQUATION ANALYSIS (PART 2)
HYDROLOGIC CHANGE ANALYSIS (PART 3)
YES
MORE MONTHS TO ANALYZE?
NO
ADDITIONAL HYDROLOGIC/ HYDRAULIC ANALYSIS REQUIRED
SEASONAL ANALYSIS
REFINED ANALYSIS

Steps one and two in the analysis are completed in two parts for each month or season of interest. First, a wetland water budget is calculated for the given month or season. Second, depths of flow, velocities, area-of-inundation, and residence time are estimated using Manning's equation.

The following discussion describes the water budget analysis, the Manning's equation analysis, the data requirements and methods, and the hydrologic change assessment for a seasonal analysis. Reference is made to the discussion of the basic analysis (Section 9.5.1) where methods are the same. In particular, note that once surface flows through the wetland are established using the water budget analysis, the Manning's equation analysis procedure is the same for basic and seasonal analyses.

Water Budget Analysis

A water budget analysis is performed to estimate surface water flows in the wetland. In a seasonal analysis flows are estimated for individual months or seasons. At a minimum two periods will be considered: (1) the driest month or season; and (2) the wettest month or season. The water budget equation relates the change in water volume stored in the wetland over a specified time interval (a month or a season) to the difference in volumetric inputs to and outputs from the wetland. The water budget equation may be written as:

$$\Delta S = P + Q_1 + Q_L + G_1 + W - Q_2 - G_2 - E$$

where: ΔS = volume change of water stored in the wetland during a specified time interval, t

t = time interval over which water budget is calculated

P = precipitation volume falling on the wetland during t

Q_1 = surface water volume flowing into the wetland at its upstream end during t

Q_L = lateral overland flow volume flowing into the wetland during t

G_1 = groundwater volume flowing into the wetland during t

W = wastewater volume applied to the wetland during t

Q_2 = surface water volume flowing out of the wetland at its downstream end during t

G_2 = groundwater volume flowing out of the wetland during t

E = evapotranspiration volume leaving the wetland during t

In a seasonal analysis, site-specific data for all of the components of the water budget will not be available. To estimate surface water flows in the wetland on a monthly or seasonal basis it is necessary to make several assumptions with respect to components of the water budget equation and to use monthly or seasonal data available for locations near the wetland site. These assumptions are discussed in the following paragraphs.

Because data on the change in storage (ΔS) will normally not be available for a wetland site on a monthly or seasonal basis, it is necessary in a seasonal analysis to assume that $\Delta S = 0$ during the wettest and driest month or season. This, of course, is not a strictly valid assumption. If we look at the effect that this assumption has on the determination of the change in wetland hydrologic and hydraulic characteristics, we find that it is a conservative assumption for dry periods and a permissive assumption for wet months. In the case of the driest month or season, the change in storage will normally be negative. That is, more water will be leaving the wetland than will be entering. Therefore, flow depths in downstream portions of the wetland under existing conditions will actually be greater than would be indicated by the seasonal analysis. At greater depths of flow, water added to a wetland will have more wetland surface area over which to spread than at lower depths. Since the seasonal depth is too low, a wastewater addition will appear to create a greater change in depth than would actually occur.

In the case of the wettest month, ΔS will be positive; that is, inputs will be greater than outputs. Consequently, flow depths in downstream portions of the wetland will actually be lower than would be indicated by a seasonal analysis. At lower depths of flow, water added to the wetland will have less wetland surface area over which to spread than at higher depths. Since the seasonal depth is too high, a wastewater addition will appear to create a smaller change in depth and area-of-inundation than would actually occur. If we remember the bias caused by the assumption that $\Delta S = 0$ when we evaluate the wetland hydrologic changes caused by a wastewater application, it is reasonable to proceed with this analytical approach.

If $\Delta S = 0$, then the water budget equation may be written with inputs to the wetland on the right and outputs from the wetland on the left of the equals sign:

$$P + Q_1 + Q_L + G_1 + W = E + Q_2 + G_2$$

Manning's Equation Analysis

Manning's equation is commonly used to characterize flow conditions in open channels and in floodplains adjacent to open channels. The Manning's equation analysis is completed in the same way for the basic and seasonal analyses. Therefore, the user should refer to Section 9.5.1 for a more complete discussion of the assumptions and use of Manning's equation. The illustration provided for Manning's equation analysis of a hypothetical wetland, Bill's Marsh, also is applicable to the seasonal analysis, also with the exception that flows estimated from the seasonal water budget analysis are used rather than annual flows.

Data Requirements

The preceding parts of Section 9.5.2 discussed the water budget analysis to estimate surface flows within the wetland and the Manning's equation analysis to estimate depths, velocities, area-of-inundation, and residence time. The data needed to support a seasonal analysis are listed in Table 9-29 along with the sources for this information.

A seasonal analysis requires a one-day site survey to obtain data on wetland area, vegetation distribution, detailed topography, and channel/wetland geometry. Wetland area and vegetation distribution should be noted on a topographic map during the walk-through survey of the site. For a closed hydrologic system, vegetation should be studied to determine the approximate location of the seasonal maximum and minimum areas-of-inundation. This determination will require the services of a wetland ecologist. Photographs of the wetland should be taken for reference purposes. These photographs can then be used in conjunction with Chow (1959) and Arcement and Schneider (1984) to estimate values for Manning's-n.

The main activity of the one-day site survey is to produce a detailed map of the wetland topography. A minimum of five transects should be made across the wetland perpendicular to the slope of the wetland. Elevations at increments of 0.5 feet should be determined in the transects. Elevations should be determined relative to an arbitrary datum such as the lowest elevation in the wetland. Distances along the transect can be measured either by pacing or with a tape measure. Elevations should be

Table 9-29. Data requirements and sources for a seasonal analysis.

Component	Source
Water Budget Analysis	
Precipitation (P)	Local Climatological Data Annual Summary
Wastewater Application (W)	Specified in system design
Surface Water Flow (Q_1, Q_L)	
Topographic map(s)	US Geological Survey
Drainage Area	Planimetered
Streamflows in area	US Geological Survey Water Resources Data for state of interest
Groundwater (G_1, G_2)	
Soil Survey	US Department of Agriculture Soil Conservation Service (County of Wetland)
Geology Reports	US Geological Survey/State Geological Survey
Evapotranspiration	
Mean monthly temperature	Local Climatological Data Annual Summary
Mean minimum monthly temperature	
Mean relative humidity at 7 a.m.	
Percentage of possible sunshine	
Wind speed	
Latitude of site	Topographic Map
Dew point temperature	Table 9-30
Solar radiation	Table 9-31
Shallow-lake evaporation	Figure 9-16
Manning's Equation Analysis	
Detailed topographic map	Site Survey
Cross-section diagrams	Site Survey
Manning's-n	Site Survey/Table 9-26
Depth of Flow	Trial and Error or Figure 9-13
Area-of-inundation	Detailed topographic map and flow depth
Velocity	Calculated
Residence time	Calculated

measured with a surveyor's rod and a hand level or transit. Transect paths should be across portions of the wetland which are representative of the wetland. Particular attention should be paid to detailing the channel geometry and the wetland geometry (shape and dimensions). A detailed topographic map and cross-section diagrams should be prepared using data from the transects.

Application to Various Wetland Hydrologic Situations

The seasonal analysis procedure is identical to that described for a basic analysis under "Application to Various Wetland Hydrologic Situations" with the exception that the water budget analysis is conducted using monthly water volumes. To apply the seasonal analysis procedure, the analyst should at a minimum: (1) identify the wettest and driest months; (2) tabulate required data for these months; (3) perform a one-day site visit to determine wetland topography, cross-section geometry, Manning's-n, and wetland slope; (4) perform the water budget analysis for each month to determine flows in the wetland; and (5) perform the Manning's-n analysis as described in Section 9.5.1. The assessment of hydrologic change should be made separately for each month.

An example of the water budget portion of a seasonal analysis is provided in this part of Section 9.5.2. The flows estimated using the seasonal water budget analysis would be used in the Manning's-n analysis in the same way as they were used in the basic analysis. Consequently, an example of the Manning's equation analysis is not provided here.

Consider the same hypothetical wetland described in the basic analysis; that is, a hydrologically open system with no channel. The wetland, Bill's Marsh, is located near Atlanta, GA and covers approximately 300 acres. It is proposed that approximately 1 million gallons per day of wastewater be applied to the wetland during the months of April through November.

The following discussion describes the seasonal water budget analysis for Bill's Marsh. This discussion includes steps 1, 4, and 15 of the procedure outlined in Section 9.5.1. The analysis is completed for the months of March and October, the wettest and driest months. Other steps outlined in the basic analysis are completed for the seasonal analysis with the exception that monthly or seasonal data are used in place of annual data.

Step 1 - Compile Required Data. Compile required data for each month. The data are for Atlanta GA.

	Month	
	March	October
Precipitation, inches	5.84	2.50
Streamflow per unit area	5.00	0.10
Drainage area above inflow	50	50
Drainage area to wetland	1	1
Mean Temperature, °F	51.1	62.4
Minimum Temperature, °F	41.1	52.3
Relative Humidity, %	78	84
Percent Sunshine, %	58	68
Wind speed, mph	10.9	8.4
Latitude, degrees	33.6	33.6

Step 4 - Calculate water budget.

To determine surface water outflow (Q_2) on a monthly or seasonal basis all of the other components of the water budget equation must be estimated from available data sources. Estimation procedures for each of the components in the water budget equation are presented below. These procedures should be completed for each of the months or seasons for which hydrologic and hydraulic analyses are desired. An illustration using a hypothetical wetland, Bill's Marsh, is provided after each component.

Precipitation (P).

1. Obtain a recent year's copy of the annual summary issue of "Local Climatological Data" for the station nearest the wetland location.

2. For each month to be analyzed, read the normal monthly precipitation, in inches per month.

3. Convert inches to a volume by multiplying by the area of the wetland.

For Bill's Marsh - March Analysis

1 and 2. Data are tabulated in step 1.

March precipitation = 5.84 inches

3. Convert to a volume.

P = 5.84 in/mo x 300 acres = 1752 acre-in/month

For Bill's Marsh - October Analysis

1 and 2. Data are tabulated in step 1.

October precipitation = 2.50 inches

3. Convert a volume.

$P = 2.50 \text{ in/mo} \times 300 \text{ acres} = 750 \text{ acre-in/month}$

Surface Water Inflow (Q_i).

1. Determine the drainage area above the upstream end of the wetland:
   a. Obtain topographic map(s) which include(s) the drainage area
   b. Outline the drainage area
   c. Measure the area using a planimeter or other drainage area measurement method.

2. Obtain a copy of "Water Resources Data" for the state in which the wetland drainage area is located.

3. Identify one or more stream gaging stations near the wetland site with drainage areas similar to that above the wetland.

4. Tabulate the measured streamflow per unit drainage area for the stations identified in step 3 for the month(s) to be analyzed. Determine an average streamflow per unit area (e.g., cubic feet per second per square mile).

5. Multiply the average streamflow per unit area (step 4) by the drainage area above the upstream end of the wetland (step 1). The resulting value is an estimate of the monthly average inflow rate to the wetland (e.g., cubic feet per second).

6. Convert to a monthly volume of water in the same units as precipitation (e.g., acre-inches per month).

For Bill's Marsh - March Analysis

1. Drainage area = 50 mi^2

2-4. Streamflow per square mile = 5.0 $\text{ft}^3/\text{sec}/\text{mi}^2$

5. March average inflow rate:

$$Q_1 = 5.0 \text{ ft}^3/\text{sec/mi}^2 \times 50 \text{ mi}^2 = 250 \text{ ft}^3/\text{sec}$$

6. March flow volume.

$$Q_1 = 250 \text{ ft}^3/\text{sec} \times 738 \text{ acre-in}/(\text{ft}^3/\text{sec})$$

$$Q_1 = 184{,}500 \text{ acre-in/month}$$

For Bill's Marsh - October Analysis

1. Drainage area = 50 mi^2

2-4. Streamflow per square mile = 0.10 ft^3/sec/mi^2

5. October average inflow rate:

$$Q_1 = 0.10 \text{ ft}^3/\text{sec/mi}^2 \times 50 \text{ mi}^2 = 5 \text{ ft}^3/\text{sec}$$

6. October flow volume:

$$Q_1 = 5 \text{ ft}^3/\text{sec} \times 738 \text{ acre-in}/(\text{ft}^3/\text{sec})$$

$$Q_1 = 3763 \text{ acre-in/month}$$

Lateral Overland Flow (Q_L).

1. Determine the drainage area contributing directly to the wetland:
   a. Use the topographic map(s) described for the surface water inflow determination
   b. Outline the drainage area contributing directly to the wetland
   c. Measure the area using a planimeter or other area measurement method.
2. Multiply the average streamflow per unit area (step 4 of the surface water inflow determination) by the drainage area directly contributing to the wetland.
3. Convert this to a monthly volume of water in the same units as precipitation (e.g., acre-inches per month).

For Bill's Marsh - March Analysis

1. Drainage area to wetland = 1 mi^2

2. March lateral inflow rate:

$$Q_L = 5.0 \text{ ft}^3/\text{sec/mi}^2 \times 1 \text{ mi}^2 = 5 \text{ ft}^3/\text{sec}$$

3. Convert to a volume:

$$Q_L = 5 \text{ ft}^3/\text{sec} \times 738 \text{ acre-in}/(\text{ft}^3/\text{sec})$$

$$Q_L = 3690 \text{ acre-in/month}$$

For Bill's March - October Analysis

1. Drainage area to wetland = 1 mi^2
2. October lateral inflow rate:

$$Q_L = 0.1 \text{ ft}^3/\text{sec/mi}^2 \times 1 \text{ mi}^2 = 0.1 \text{ ft}^3/\text{sec}$$

3. Convert to a volume:

$$Q_L = 0.1 \text{ ft}^3/\text{sec} \times 738 \text{ acre-in}/(\text{ft}^3/\text{sec})$$

$$Q_L = 73.8 \text{ acre-in/month}$$

Groundwater Inflow or Outflow (G_1 or G_2).

1. Obtain soil survey and geological reports for the county in which the wetland is located. Soil surveys are obtained from the US Department of Agriculture Soil Conservation Service in the county where the wetland is located. Geological reports may be obtained from the state geological survey.
2. List the soils and geology underlying the wetland. For each soil, list its permeability or drainage characteristics (poorly drained, moderately drained, well drained). Look for evidence of confining soil or rock layers under the wetland.
   a. If a confining layer exists or is indicated, assume G_1 G_2 = 0.
   b. If a confining layer does not exist or is not indicated, the analyst should be cautious about using this method since seepage losses may be significant. In applying this method, assume G_1 = G_2 = 0.
   c. If no information is available, assume $G_1 = G_2 = 0$.

For Bill's Marsh - March Analysis

Assume groundwater flow = 0 acre-in/month

For Bill's Marsh - October Analysis

Assume groundwater flow = 0 acre-in/month

Wastewater Application (W).

1. The wastewater application rate is zero for existing conditions unless wastewater is currently being applied.

2. The wastewater application rate must be specified for the evaluation of hydrologic change due to a wastewater application. The application rate should be converted to the same volumetric units as precipitation (e.g., acre-inches per month) (1 million gallons per day (MGD) equals 1.55 cubic feet per second or about 1100 acre-inches per 30-day month).

For Bill's Marsh - March Analysis

Wastewater Flow (existing conditions) = 0 acre-in/month

For Bill's Marsh - October Analysis

Wastewater flow (existing conditions) = 0 acre-in/month

Evapotranspiration (E).

1. Obtain a recent year's copy of the annual summary issue of "Local Climatological Data" for the station nearest the wetland location. Use the table titled: "Normals, Means, and Extremes."

2. For the month of interest, tabulate the following data: (1) mean temperature in degrees F; (2) minimum temperature in degrees F; (3) relative humidity at 7 a.m.; (4) mean wind speed in miles per hour; (5) percentage of possible sunshine; and (6) the latitude of the station.

3. Estimate the mean dew point temperature in degrees F from Table 9-30 using the minimum temperature in degrees F and the relative humidity in percent.

4. Calculate the mean wind movement in miles per day by multiplying wind speed in miles per hour by 24 hours.

5. Determine the correction factor for converting maximum solar radiation (IX) to actual solar radiation (I) based on average sunshine (u) as follows:

$$I/IX = 0.61u + 0.35$$

This adjustment is made based on List (1966).

Table 9-30. Dew point temperature as a function of relative humidity and temperature.

Temperature (degrees F)	Relative Humidity (percent)							
	55	60	65	70	75	80	85	90
25	13	14	16	18	19	20	21	23
30	18	20	21	23	24	25	26	27
35	21	23	26	28	29	30	31	33
40	26	28	29	31	33	34	36	37
45	30	32	34	36	37	39	41	42
50	34	37	39	41	42	44	46	47
55	38	41	43	45	48	50	51	52
60	44	46	48	50	52	54	55	57
65	49	51	53	55	57	58	60	62
70	53	55	57	60	62	64	65	67
75	57	60	62	64	66	69	71	72
80	62	65	67	68	72	73	75	77

Source: Miller and Thompson 1970.

Using the station latitude and the month, read the maximum solar radiation (IX) from Table 9-31. Assume a transmission coefficient of a = 0.8 unless there is a basis for using other coefficients. Multiply the maximum solar radiation by the correction factor (I/IX) to determine solar radiation in Langleys per day.

6. Use the nomograph in Figure 9-16 to estimate daily lake evaporation.

7. Calculate monthly evapotranspiration in inches by multiplying daily lake evaporation in inches by the number of days in the month of interest.

8. Convert this to a volume by multiplying by the wetland area. Units should be the same as precipitation (e.g., acre-inches per month).

For Bill's Marsh - March Analysis

1-2. Data are tabulated under step 1.

3. Estimate dew point:

Minimum Temperature = 41.1°F
Relative Humidity = 78%

For 40°F, dew point is 33°F at 75% relative humidity and it is 34°F at 80%. Therefore, at 40°F and 78% relative humidity dew point is approximately 34°F.

For 45°F, dew point is 37°F at 75% relative humidity and it is 39°F at 80%. Therefore, at 45°F and 78% relative humidity dew point is approximately 38°F.

Since 41°F (minimum temperature) is one-fifth of the way between 40°F and 45°F, the dew point temperature is one-fifth of the way between 34°F and 38°F. Therefore, dew point is approximately 35°F.

4. Mean wind movement:

wind = 10.9 mi/hr x 24 hr/day = 261.6 mi/day

5. Determine solar correction factor for average sunshine = 58% = 0.58

$$I/IX = 0.61u + 0.35$$

$$I/IX = 0.61\ (0.58) + 0.35$$

$$I/IX = 0.70$$

Estimate IX at latitude 33.6° N for March from Table 9-31 (a = 0.8),

$$IX \text{ at } 30° \text{ N} = 539 \text{ cal/cm}^2$$

$$IX \text{ at } 40° \text{ N} = 456 \text{ cal/cm}^2$$

Since 33.6° N is 64% of the way between 40° N and 30° N, IX is 64% of the way between 456 and 539 cal/cm^2.

$$IX = (539-456)\ (0.64) + 456$$

$$IX = 509 \text{ cal/cm}^2$$

Estimate actual solar radiation:

$$I = IX\ (I/IX)$$

$$I = (509 \text{ cal/cm}^2)\ (0.70)$$

$$I = 356 \text{ cal/cm}^2$$

6. Estimate daily lake evaporation from Figure 9-16:
air temperature = 51.1 degrees F
dew point = 35 degrees F
wind movement = 261.6 mi/day

solar radiation = 356 cal/cm^2

Evaporation = 0.145 inches/day

7. Monthly evapotranspiration

E = 0.145 in/day x 31 days = 4.50 inches/month

8. Convert to a volume:

E = 4.50 inches/mo x 300 acres = 1350 acre in/month

For Bill's Marsh - October Analysis

1-2. Data are tabulated under step 1.

3. Estimate dew point:

Minimum Temperature = 52.3° F
Relative Humidity = 84%

For 50°F, dew point is 44°F at 80% relative humidity and it is 46°F at 85%. Therefore, at 40°F and 84% relative humidity dew point is approximately 46°F.

For 55°F, dew point is 50°F at 80% relative humidity and it is 51°F at 85%. Therefore, at 55°F and 84% relative humidity dew point is approximately 51°F.

Since 52.3°F (minimum temperature) is one-half of the way between 50°F and 55°F, the dew point temperature is one-half of the way between 46°F and 51°F. Therefore, dew point is approximately 48°F.

4. Mean wind movement

wind = 8.4 mi/hr x 24 hr/day = 201.6 mi/day

5. Determine solar correction factor for average

Sunshine = 68% = 0.68

$I/IX = 0.61\ S + 0.35$

$I/IX = 0.61(0.68) + 0.35$

$I/IX = 0.76$

Estimate IX at latitude 33.6° N for October from Table 9-31 (a = 0.8), use IX half way between September and November values.

IX at 30° N = 446 cal/cm^2

IX at 40° N = 348 cal/cm^2

Since 33.6°N is 64% of the way between 40°N and 30° N, IX is 64% of the way between 348 and 446 cal/cm^2.

$IX = (446-348)\ (0.64) + 348$

$IX = 411\ cal/cm^2$

Table 9-31. Maximum solar radiation reaching the ground for various atmospheric transmission coefficients.

TOTAL DAILY DIRECT SOLAR RADIATION REACHING THE GROUND WITH VARIOUS ATMOSPHERIC TRANSMISSION COEFFICIENTS

The solar constant J_o is assumed to be 1.94 cal. cm.$^{-2}$ min.$^{-1}$ Values apply to a horizontal surface.

Longitude of the sun / Approximate date

Transmission coefficient $a = 0.6$

cal. cm.$^{-2}$

Latitude	0° Mar. 21	45° May 6	90° June 22	135° Aug. 8	180° Sept. 23	225° Nov. 8	270° Dec. 22	315° Feb. 4
90°		127	299	125				
80	6	158	309	156	5			
70	47	234	349	232	46			
60	120	312	406	308	118	10		10
50	202	376	450	372	199	58	19	58
40	282	426	477	421	278	130	75	131
30	350	453	481	449	345	213	152	215
20	404	459	465	454	398	293	237	296
10	436	444	428	439	430	366	323	370
0	447	407	372	404	440	422	397	427
−10	436	353	303	349	430	461	457	465
−20	404	282	222	279	398	475	497	480
−30	350	206	143	204	345	470	514	475
−40	282	125	70	124	278	441	509	445
−50	202	56	18	55	199	391	481	395
−60	120	10		10	118	323	434	327
−70	47				46	242	373	245
−80	6				5	164	330	166
−90						131	319	133

Transmission coefficient $a = 0.8$

Latitude	0° Mar. 21	45° May 6	90° June 22	135° Aug. 8	180° Sept. 23	225° Nov. 8	270° Dec. 22	315° Feb. 4
90°		349	615	346				
80	29	365	608	361	29			
70	128	434	605	429	126	1		1
60	242	520	650	515	240	44	5	44
50	356	591	686	585	350	136	64	137
40	456	641	708	635	449	247	164	249
30	539	668	706	662	532	360	277	363
20	601	669	678	663	593	463	393	468
10	639	649	630	643	630	555	503	560
0	652	602	560	597	643	626	598	631
−10	639	534	471	530	630	673	672	680
−20	601	446	369	442	593	695	725	700
−30	539	347	260	343	532	694	754	700
−40	456	239	153	236	449	665	756	671
−50	356	131	60	130	350	612	732	619
−60	242	42	4	42	240	539	694	544
−70	128	1		1	126	449	646	454
−80	29				29	378	649	381
−90						363	656	366

Longitude of the sun / Approximate date

Transmission coefficient $a = 0.7$

cal. cm.$^{-2}$

Latitude	0° Mar. 21	45° May 6	90° June 22	135° Aug. 8	180° Sept. 23	225° Nov. 8	270° Dec. 22	315° Feb. 4
90°		217	440	215				
80	13	243	442	242	13			
70	80	324	467	321	79			
60	174	408	520	404	172	22	1	23
50	272	477	563	472	268	91	37	92
40	363	529	587	524	358	182	111	184
30	440	556	588	550	434	281	210	283
20	499	561	568	556	491	374	309	378
10	534	542	524	537	527	456	408	460
0	546	501	462	496	538	519	493	524
−10	534	439	382	436	527	563	560	568
−20	499	361	290	357	491	582	606	588
−30	440	271	196	268	434	576	628	582
−40	363	176	103	174	358	548	627	554
−50	272	88	34	87	268	495	601	500
−60	174	22	1	21	172	423	555	427
−70	80				79	337	499	340
−80	13				13	253	472	255
−90						226	469	228

Transmission coefficient $a = 0.9$

Latitude	0° Mar. 21	45° May 6	90° June 22	135° Aug. 8	180° Sept. 23	225° Nov. 8	270° Dec. 22	315° Feb. 4
90°		532	826	526				
80	67	528	813	523	66			
70	199	571	774	566	196	5		5
60	333	650	799	643	328	80	16	81
50	455	718	828	711	449	200	107	201
40	562	766	841	759	554	328	229	331
30	651	791	831	783	641	453	362	458
20	715	789	799	781	705	566	491	571
10	755	763	744	756	744	664	610	670
0	768	714	668	707	757	740	713	748
−10	755	640	571	634	744	792	794	799
−20	715	545	460	539	705	819	853	826
−30	651	436	340	433	641	820	888	828
−40	562	316	214	313	554	794	898	802
−50	455	192	100	190	449	745	884	752
−60	333	77	15	76	328	674	854	681
−70	199	5		4	196	593	826	598
−80	67				66	547	867	553
−90						551	883	556

Estimate actual solar radiation:

$I = IX\ (I/IX)$

$I = (411\ \mathrm{cal/cm^2})\ (0.76)$

$I = 312\ \mathrm{cal/cm^2}$

6. Estimate daily lake evaporation from Figure 9-16

air temperature = 62.4°F
dew point = 48°F
wind movement = 201.6 mi/day

solar radiation = 312 $\mathrm{cal/cm^2}$

Evaporation = 0.095 inches/day

7. Monthly evapotranspiration

$E = 0.095$ in/day x 31 days = 2.94 inches/month

8. Convert to a volume:

$E = 2.94$ inches/mo x 300 acres

$E = 882$ acre-inches/month

Surface Water Outflow (Q_2).

1. Estimate total monthly volume of water leaving the wetland as streamflow by solving the monthly water budget equation for Q_2.

2. Convert to a flowrate in units of $\mathrm{ft^3}$ per second. If you have been using units of acre-inches per month, you should convert by multiplying by 43560 $\mathrm{ft^2}$ per acre, divide by 12 inches per ft, and divide by the number of seconds in the month of interest.

For Bill's Marsh - March Analysis

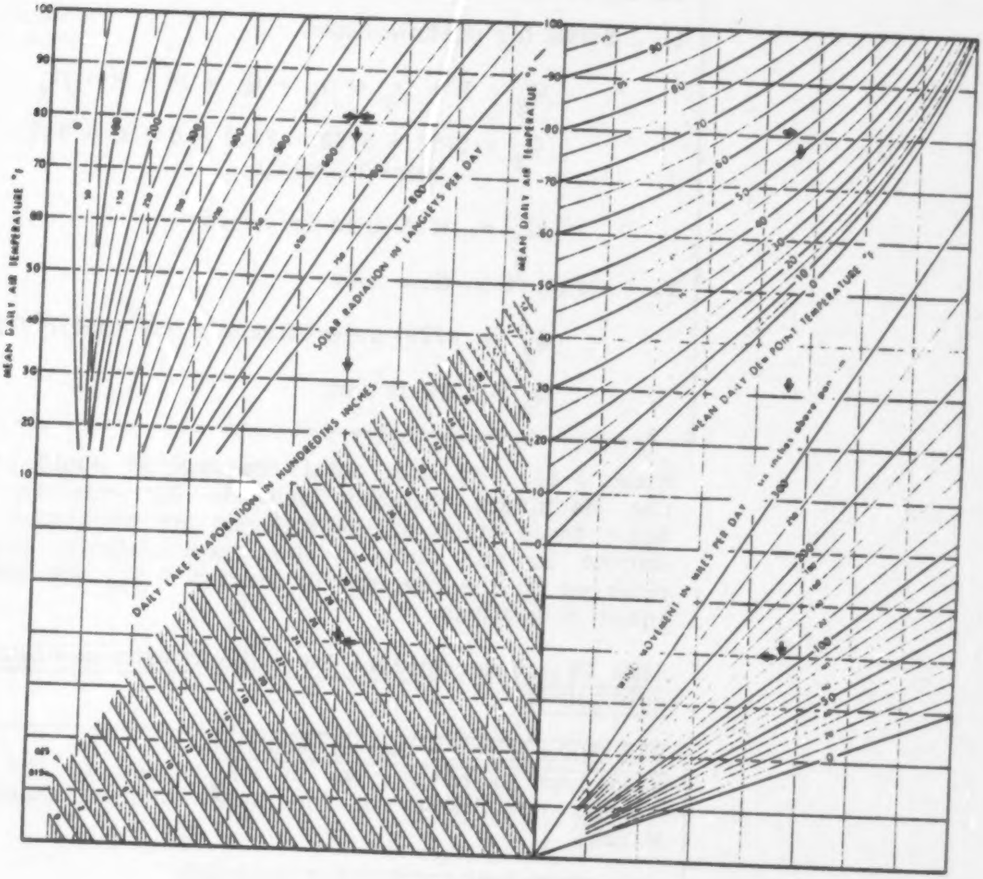
1. Solve for outflow rate:

$$Q_2 = P + Q_1 + Q_L + G_1 + W - E - G_2$$

$$Q_2 = (1752 + 184500 + 3690 + 0 + 0 - 1350 - 0)\ \text{acre-in/month}$$

$$Q_2 = 188{,}592\ \text{acre-in/month}$$

Figure 9-16. Shallow lake evaporation as a function of solar radiation, air temperature, dew point, and wind movement.



Source: Linsley et al. 1975

2. Convert to flow:

$$Q_2 = 188{,}592 \text{ acre-in/month } (\text{ft}^3/\text{sec})/(738 \text{ acre-in})$$

$$Q_2 = 255 \text{ ft}^3/\text{sec}.$$

For Bill's Marsh - October Analysis

1. Solve for outflow rate:

$$Q_2 = P + Q_1 + Q_L + G_1 + W - E - G_2$$

$$Q_2 = (750 + 3763 + 73.8 + 0 + 0 - 882 - 0) \text{ acre-in/month}$$

$$Q_2 = 3705 \text{ acre-in/month}$$

2. Convert to flow rate

$$Q_2 = 3705 \text{ acre-in/month } (\text{ft}^3/\text{sec})/(738 \text{ acre in})$$

$$Q_2 = 5.02 \text{ ft}^3/\text{sec}$$

Steps 5-14. At this point the analyst would proceed with the Manning's equation analysis for existing conditions. Since these steps of the analysis are completed in the same manner as was done in the basic analysis, the reader is referred to the example in Section 9.5.1 for the Manning's equation analysis.

Step 15 - Water budget for wetland with wastewater application.

For Bill's Marsh - March Analysis

Since no wastewater is to be applied to the wetland in March, no change in the water budget should occur in March.

For Bill's Marsh - October Analysis

In computing the water budget for October, it is assumed that precipitation, groundwater, surface water inflow, and evapotranspiration remain unchanged. Consequently flows in the wetland will increase by an amount equal to the wastewater application rate:

$$W = 1 \text{ MGD} = 1.55 \text{ ft}^3/\text{sec}$$

Average outflow (Q_2) will increase from 5.1 ft^3/sec to 6.6 ft^3/sec in October

The seasonal analysis would continue with the Manning's equation analysis and the evaluation of hydrologic changes.

9.5.3 Refined Analysis

A refined analysis is performed when a seasonal analysis indicates the possibility of significant alterations of wetland hydrology due to the application of wastewater to the wetland. A refined analysis also is performed if flow characteristics through the wetland are altered and effective pollutant removal is reduced because of reduced residence time (increased velocities). The analysis procedure is the same as the procedure used in the seasonal analysis except that it requires the collection of site-specific data. These data, collected over a period of one year, would be compared to results predicted in the seasonal analysis. The results of the seasonal analysis are based on the not strictly valid assumption that the change in water storage is zero from month to month. In addition, the assumption of zero groundwater flow, which frequently is made in a seasonal analysis, may also be incorrect. Therefore, monthly data on all components of the water budget, as well as depths of flow, velocities of flow, and area-of-inundation in the wetland must be collected to test the seasonal analysis results. If actual wetland hydrologic characteristics are significantly different from analyzed characteristics, water budget analysis assumptions and Manning's equation analysis parameters must be modified and the seasonal analysis procedure should be repeated.

Water Budget Analysis

A water budget is developed using site-specific data. The water budget developed in a refined analysis is compared with that developed for the seasonal analysis to determine potential sources of error in the seasonal analysis. Adjustments in the seasonal analysis assumptions and resulting water budget would then be made so that predicted wetland surface outflows would more closely match those observed under the refined analysis field study. The seasonal analysis procedure could then be used to predict flows when wastewater is applied to the wetland.

Manning's Equation Analysis

Refined analysis field observations of flow depths and velocities for various flows should be compared with depths and flows predicted in the seasonal analysis. Based on this comparison the application of Manning's equation to the wetland could be modified. Modifications might include changing Manning's-n or reducing the effective flow width of the wetland. This latter modification might be necessary if stagnant or backflow conditions exist at the margins of the wetland or if the margins are not expected to carry any of the additional flows anticipated from the wastewater application.

Data Requirements

The data required to support a refined analysis are listed in Table 9-32. Data must be collected for the site for a minimum of one year. Data collection methods for each of the water budget components are briefly described below.

Precipitation. A rain gauge should be installed as near to the center of the wetland as is consistent with security and access considerations. The gage should be read and emptied once every week on a day when no rain is falling.

Evaporation. A standard Class A evaporation pan should be installed near the rain gauge. The pan should be read weekly.

Groundwater. Groundwater monitoring wells should be installed at a minimum of five locations in the wetland. One should be located near the center of the wetland. The four other wells should be installed at approximately the outside boundary of the wetland at one-third and two-thirds the distance down the length of the wetland on either side of the central axis of the wetland. All wells should be surveyed in with elevations established with respect to an arbitrary datum (e.g., the elevation of the downstream end of the wetland). Groundwater elevation (depth) should be measured monthly.

In addition, two of the wetland boundary wells should be used for falling head permeability tests to determine the soil permeability. These tests should be conducted once during a dry period and once during a wet period.

Surface Water Inflows and Outflows. All well-defined surface water inflows and outflows should be monitored continuously using water-level recorders. Stage-discharge relationships must be developed for each water-level recorder location. The stage-discharge relationships are determined by measuring water-level, velocities across the stream, and the cross-sectional area of the stream under various flow conditions. Additional information on streamflow measurement can be found in Linsley et al. (1975).

Table 9-32. Data requirements for a refined analysis.

Component	Method	Frequency
Water Budget Analysis		
Precipitation	Rain gauge	Weekly
Evapotranspiration	Class-A Pan	Weekly
Groundwater Flow		
Permeability	Falling Head Permeability	Two times
Groundwater Level	Monitoring Wells	Monthly
Surface Water Flow		
Water Level	Water Level Recorders	Continuously
Velocity	Current Meter	Monthly
Area	Survey of Channel	Monthly
Water Storage		
Water Depth	Metal Posts-surveyed in	Monthly
Wetland Topography	Site Survey	One time
Manning's Equation Analysis		
Manning's-n	Site Survey Chow (1959) Arcement and Schneider (1984)	Winter and Summer
Wetland Slope	Site Survey Topographic Map	One time
Channel/Wetland Geometry	Site Survey Cross-section Diagrams	One time

Water Surface Elevation. The elevation of the water surface relative to the arbitrary datum established for the groundwater wells should be measured at a minimum of six locations in the wetland on a monthly basis. The elevation is measured by installing and surveying in metal posts along two cross-sections of the wetland perpendicular to the axis of the wetland. The first cross-section should be located approximately one-third the length of the wetland from the upstream end of the wetland. Metal posts should be installed at the lowest ground surface elevation on the cross-section and approximately one fourth the distance from the lowest elevation to the edge of the wetland on either side of the central axis of the wetland. The second cross-section should be located approximately one-third the length of the wetland from the downstream end of the wetland. Metal posts should be installed in the same way as for the first cross-section.

Velocity. Dye or other tracer studies should be conducted to determine the mean velocities of flow in the wetland. These studies should be conducted monthly to obtain a better picture of the wetland response to water inputs.

Site Survey. A site survey should be conducted at the same time that groundwater wells and water depth metal posts are surveyed in. A minimum of five transects should be made across the wetland perpendicular to the central axis of the wetland. Elevations at intervals of 0.5 feet should be determined in the transects. Elevations should be established relative to an arbitrary datum such as the downstream end of the wetland. Transects should be across portions of the wetland which are representative of the wetland. Particular attention should be paid to detailing the channel geometry and the wetland geometry (shape and dimensions). A detailed topographic map and cross-section disgrams should be prepared using site survey data.

Wetland area and vegetation distribution should be noted on a topographic map during the site survey. Photographs of the wetland should be taken for reference purposes two times during the year. These photographs can be compared with photographs in Chen (1959) and Areement and Schneider (1984) to estimate values for Manning's-n at various locations in the wetland during the winter and during the summer.

Application to Various Hydrologic Wetland Situations

As indicated previously, the refined analysis is completed by following the seasonal analysis procedure. Data used in the refined analysis are those measured in the year-long data collection effort. The flows observed during the field data collection effort should be compared to those estimated by the refined water budget analysis. If these are similar, then the water budget is balanced; if they are not similar, then there is a source or sink for water which was not measured during the refined analysis sampling program. This source or sink should be identified and an effort should be made to quantify it.

Once the refined analysis water budget is balanced, values of its components should be compared to the values of the components of the seasonal analysis water budget analysis. Particular attention should be paid to verifying that the assumptions of no change in storage ($\Delta S = 0$) and no net groundwater flow ($G_2 = G_1 = 0$) are reasonable. If these assumptions are reasonable, the Manning's equation analysis can proceed by randomly selecting months in a year without computing carry-over water storage on a month-to-month basis. If these assumptions are not reasonable, a continuous water budget analysis will have to be performed by starting with the driest month of the year and computing water budgets for each succeeding month until all twelve months have been analyzed and flows have been generated. Flows then should be compared with those observed during the refined analysis field study.

Next, the Manning's equation analysis should be performed using flows and cross-section geometry measured in the field data collection effort. Flow depths predicted by the analysis should be compared with those measured. If depths differ significantly, the analyst should consider adjusting Manning's-n or altering the geometric configuration used in the analysis until reasonable agreement between observed and analysis-predicted depths is achieved.

After the Manning's equation analysis has been adjusted to generate reasonable fits to the observed data on flow depths, computed flow rates should be divided by computed cross-sectional areas of flow to estimate flow velocities. These velocities should be compared with velocities measured in the field. If observed and predicted values differ significantly, a velocity adjustment factor should be estimated for each of the wetland cross-sections.

When the refined analysis evaluation of existing conditions is complete, the water budget and Manning's equation procedures should be "calibrated" to the wetland. It should then be possible to predict the changes in water surface elevation, area-of-inundation, velocity, and residence time due to the application of wastewater to the wetland. If the refined analysis procedures do not result in a "calibrated" water budget and Manning's equation analysis, it may be necessary to consider more advanced computer-based modeling techniques. These are discussed in Section 3.3.4.

9.5.4 Glossary of Variables

Contained in this section is a list of variables included in Section 9.5. The list includes the variable symbol and a description.

Symbol	Description
a	Solar transmission coefficient
d	Depth of flow
e_1	Upstream elevation in wetland
e_2	Downstream elevation in wetland
g	Net groundwater flow
h	Manning's roughness coefficient
t	Time
w	Bottom width of geometric cross-section
A	Cross-sectional area of geometric section
A_{app}	Area-of-inundation with wastewater application
A_w	Area of wetland
B	Bank height of channel
C	Constant for Manning's-n equation analysis
E	Evapotranspiration
G_1	Groundwater flow into wetland
G_2	Groundwater flowing out of wetland
I	Actual solar radiation (water budget analysis)
IX	Solar radiation without attenuation (maximum solar radiation)
K	Empirical constant for control section (culvert) calculations
L	Bottom width of weir
P	Precipitation (water budget analysis)
P	Wetted perimeter (Manning's equation analysis)
Q	Streamflow
Q_F	Streamflow when depth of flow equals bank height
Q_L	Lateral inflow to wetland
Q_o	Streamflow overtopping channel on to floodplain
Q_1	Streamflow flowing into wetland
Q_2	Streamflow flowing out of wetland
R	Hydraulic radius (Manning's equation analysis)

S	**Slope of wetland (Manning's equation analysis)**
ΔS	**Change in water stored in wetland**
T	**Residence time**
u	**Fraction of total sunshine possible (water budget analysis)**
V	**Velocity of flow**
Z	**Side slope of geometric section**

9.6 AGENCY RESPONSIBILITIES AND DATA SOURCES

The importance of working with the appropriate regulatory agencies has been stressed throughout the Handbook. The Water Quality Standards and NPDES programs as administered by EPA and state agencies will largely determine what information is necessary to assess and permit a prospective wetlands discharge. If an acceptable wetland site is identified and the discharge can be permitted, additional data may be necessary for engineering planning.

Besides their responsibilities for administering programs, numerous federal, state, regional and local agencies serve as data sources. These agencies can supply data that are useful throughout the project planning and sampling program design processes. The agencies responsible for administering programs and collecting data vary from state to state. Tables 9-25 through 9-32 indicate the pertinent administrative and data collection agencies in each Region IV state. Some federal agencies with wetlands jurisdiction or involvement have district or state offices. These are listed on Tables 9-33 through 9-37. State Natural Heritage Programs help define wetlands of special significance and can be a valuable source of information for identifying unique or endangered wetlands and their locations. These agencies are listed in Table 9-38. Certain agencies have responsibility for collecting data on a national level (e.g., soils data by the Soil Conservation Service). The agencies with specific data collection responsibilities are listed in Table 9-39.

Table 9-33 Agency Responsibilities and Data Sources - ALABAMA

Area of Jurisdiction	Federal	State	Regional/Local
1. Water Quality Standards Program	EPA Region IV	Department of Environmental Management (DEM) Water Division State Office Building Montgomery, AL 36130 205/271-7700	
2. NPDES Permit Program	EPA Region IV	DEM, see Water Quality Standards Program	
3. Construction Grants Program	EPA Region IV	DEM, see Water Quality Standards Program	
4. Planning			
- Land use (general--population projections, development trends, etc.)		Office of State Planning & Federal Programs (OSPFP) 3734 Atlanta Highway Montgomery, AL 36130 205/832-6400	Regional Planning Commissions[1] City/County Planning Depts.
- Archeological/Historical		Historical Commission 725 Monroe Street Montgomery, AL 36130 205/832-6621	
- A-95 Review/State Clearinghouse		OSPFP, see Land Use	
5. Geomorphology			
- Wetlands Identification	Fish and Wildlife Service	DEM, see Water Quality Standards Program	
		Dept. of Conservation and Natural Resources (DCNR) State Lands Division (SLD) 64 North Union St. Montgomery, AL 36130 (205) 832-6330	
- Geological data	Geological Survey	DEM, see Water Quality Standards Program	
- Dredge & Fill Permits	Army Corps of Engineers	DEM, see Water Quality Standards Program	
		SLD, see Wetlands Identification	
6. Hydrology/Meteorology			
- Flow data	Geological Survey	DEM, see Water Quality Standards Program	
- Floodplain management	Federal Emergency Management Administration	Building Commission 800 South McDonough St. Montgomery, AL 36104 205/832-3404	Regional Planning Commissions[1] City/County Planning Depts.
- Groundwater Data	Geological Survey	DEM, see Water Quality Standards Program	County Public Health Depts.
- Meteorologic Data	National Weather Service		
7. Water Quality (see Nos. 1, 2, & 3)			
- Water Quality Data	Environmental Protection Agency	DEM, see Water Quality Standards Program	Utilities County Public Health Depts. Universities
	Geological Survey		
	Army Corps of Engineers		
8. Ecology			
- Protected Species	Fish and Wildlife Service	Dept. of Conservation and Natural Resources Division of Game & Fish (DGF) Administrative Building 64 North Union Street Montgomery, AL 36130 205/832-6300	
- Wildlife		DGF, see Protected Species	
- Rare or endangered Wetlands (see Section 2.)			
- Wetlands in coastal zones zones		Coastal Area Board P.O. Box 755 Daphne, AL 36526 205/626-1880	

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[1] See list of Regional Planning Commissions

[1] Alabama Regional Planning and Development Commissions

Northwest Alabama Council of Local
Governments
P O Box 2603
Muscle Shoals, AL 35660

North Central Alabama Regional Council
of Governments
City Hall Tower - 5th Floor
P O Box C
Decatur, AL 35602

Birmingham Regional Planning Commission
2112 Eleventh Avenue, South
Magnolia Office Park, Suite 220
Birmingham, AL 35256

West Alabama Planning and Development
Council
Tuscaloosa Municipal Airport
Terminal Building, 2nd Floor
P O Drawer 408
Northport, AL 35476

Alabama-Tombigbee Regional Commission
P O Box 269
Camden, AL 36726

South Alabama Regional Planning
Commission
International Trade Center
250 North Water Street
P O Box 1665
Mobile, AL 36633

Top of Alabama Regional Council
of Governments
115 Washington St. SE
Huntsville, AL 35801

East Alabama Regional Planning
and Development Commission
P O Box 2186
Anniston, AL 36202

Lee County Area Council
of Governments
P O Box 1072
Auburn, AL 36831

Southeast Alabama Regional
Planning and Development Comission
207 Plaza 2
U.S. Highway 231 at Ross Clark Circle
P O Box 1406
Dothan, AL 36302

South Central Alabama
Development Commission
2815 W. South Blvd.
Governors Square Shopping Center
Montgomery, AL 36116

Lower Chattahoochee Area Planning
and Development Commission
Box 1908
Columbus, GA 31902

Table 9-34 Agency Responsibilities and Data Sources - FLORIDA

Area of Jurisdiction	Federal	State	Regional/Local
1. Water Quality Standards Program	EPA Region IV	Dept. of Environmental Regulation (DER)[1] Division of Environmental Programs 2600 Blair Stone Road Twin Towers Office Building Tallahassee, FL 32301 904/488-0130	
2. NPDES Permit Program	EPA, Region IV	DER, see Water Quality Standards Program	
3. Construction Grants Program	EPA Region IV	DER, see Water Quality Standards Program	
4. Planning			
- Land Use (DRI)		Dept. of Veteran and Community Affairs Bureau of Land and Water Management (BLWM) Carlton Building, Room 530 Tallahassee, FL 32301 904/488-4925	Regional Planning Council[3]
- Land use (general--population projections, development trends, etc.)			Regional Planning Councils[3] City/County Planning Departments
- Archeological/Historical		Department of State, Division of Archives, History and Records Management Bureau of Historic Sites and Properties The Capitol Tallahassee, FL 32301 904/487-2333	
- A-95 Review/State Clearinghouse		State Planning and Development Clearinghouse Bureau of Intergovernmental Relations Division of State Planning, Dept. of Administration Carlton Building, Room 530 Tallahassee, FL 32301	
5. Geomorphology			
- Wetlands Identification	Fish and Wildlife Service	DER, see Water Quality Standards Program Department of Natural Resources (DNR) 3900 Commonwealth Blvd. Tallahassee, FL 32303 904/388-3180	
- Geological data	Geological Survey	DNR, see Wetlands Identification	
- Dredge and Fill Permits	Army Corps of Engineers	DER, see Water Quality Standards Program DNR, see Wetlands Identification	
6. Hydrology/Meteorology			
- Flow data	Geological Survey	Water Management Districts	
- Floodplain Management	Federal Emergency Management Administration	Water Management Districts[2] State Organized Authorities (e.g., Santa Rosa Island Authority)	Regional Planning Councils[2] City/County Planning Depts.
- Groundwater Data	Geological Survey	Water Management Districts[2] DNR, see Wetlands Identification	County Public Health Depts.
- Meteorologic Data	National Weather Service		

Table 9-34 (Continued)

Area of Jurisdiction	Federal	State	Regional/Local
7. Water Quality (see Nos. 1, 2 & 3) - Water Quality Data	Environmental Protection Agency	DER, see Water Quality Standards Program	Utility Authorities County Public Health Depts. County Environmental Depts. Universities
	Geological Survey	Water Management Districts[2]	
	Army Corps of Engineers	Water Management Districts[4]	
8. Ecology - Protected species	Fish and Wildlife Service	Game and Freshwater Fish Commission (GFFC) 620 S. Meridian St. Tallahassee, FL 32301 904/488-6661	
- Wildlife		GFFC, see Protected Species	
- Rare or endangered wetlands (see Section 2.)			
- Areas of Critical State Concern		BLWM, see Land Use (DRI)	

[1] See list of DER Regional Offices
[2] See list of Florida Water Management Districts
[3] See list of Florida Regional Planning Councils

[1] Florida Department of Environmental Regulation District Offices

Northwest District
160 Governmental Center
Pensacola, FL 32561
904/436-8300

Northwest District Branch Office
217 E. 23rd St.
Suite B
Panama City, FL 32405
904/769-3576

Northwest District Branch Office
Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, FL 32301
904/488-3704

St. Johns River Subdistrict
3426 Bills Road
Jacksonville, FL 32207
904/396-6959

St. Johns River Subdistrict Branch Office
825 Northwest 23rd Ave., Suite G
Gainesville, FL 32601
904/377-7528

Southwest District
7601 Highway 301 North
Tampa, FL 33610
813/985-7402

South Florida Branch Office
11400 Overseas Highway
Suites 219-224
Marathon, FL 33050
305/743-5955 or 9251

South Florida Subdistrict
3301 Gun Club Road
P.O. Box 3858
West Palm Beach, FL 33402
305/689-5800

South Florida Subdistrict Branch Office
2745 Southeast Morningside Blvd
Port St. Lucie, FL 33452
305/878-3890

South Florida District
2269 Bay Street
Fort Myers, FL 33901
813/332-2667

South Florida Branch Office
3201 Golf Course Blvd.
Punta Gorda, FL 33950
813/639-4967

[2] Florida Water Management Districts

Northwest Florida Water Management District
R. 1 Box 3100
Havanna, FL 32333
904/487-1770

Suwannee River Water Management District
Rt. 3. Box 64
Live Oak, FL 32060
904/362-1001

St. Johns River Water Management District
P.O. Box 1425
Palatka, FL 32077
/796-7211

Southwest Florida Water Management District
5600 U.S. Highway 41 South
Brooksville, FL 33512
904/796-7211

South Florida Water Management District
P.O. Box V
West Palm Beach, FL 33402
305/686-8800

[3] Florida Regional Planning Councils

West Florida Regional Planning Council
P.O. Box 486
Pensacola, FL 32593
904/478-5870

Apalachee Regional Planning Council
P.O. Box 428
Blountstown, FL 32424
904/674-4571

North Central Florida Regional Planning Council
2002 N.W. 16th St.
Gainesville, FL 32601
904/376-3344

Northeast Florida Regional Planning Council
8641 Baypine Road, Suite 9
Jacksonville, FL 32216
904/737-7311

Withlacoochee Regional Planning Council
1241 S.W. 10th St.
Ocala, FL 32670
904/732-3307

East Central Florida Regional Planning Council
1011 Wymore Road
Winter Park, FL 32789
305/645-3339

Central Florida Regional Planning Council
P.O. Drawer 2089
Bartow, FL 33830
813/533-4146

Tampa Bay Regional Planning Council
9455 Koger Blvd.
St. Petersburg, FL 33702
813/588-5151

Southwest Florida Regional Planning Council
2121 West First Street
Ft. Myers, FL 33902
813/334-7382

Treasure Coast Regional Planning Council
P.O. Box 2395
Stuart, FL 33494
305/286-3313

South Florida Regional Planning Council
1515 Northwest 167th St., Suite 429
Miami, FL 33169
305/621-5871

Table 9-35 Agency Responsibilities and Data Sources - GEORGIA

Area of Jurisdiction	Federal	State	Regional/Local
1. Water Quality Standards Program	EPA Region IV	Dept. of Natural Resources (DNR) Environmental Protection Division (EPD) 270 Washington Street, S.W. Atlanta, GA 30334 404/656-4713	
2. NPDES Permit Program	EPA Region IV	EPD, see Water Quality Standards Program	
3. Construction Grants Program	EPA Region IV	EPD, see Water Quality Standards Program	
4. Planning			
- Land use (general--population projections, development trends, etc.)			Area Planning and Development Commissions (APDC) City/County Planning Depts.
- Archeological/Historical		DNR State Historic Preservation Office 270 Washington Street SW, Room 701 Atlanta, GA 30334 404/656-2840 State Archeologist West Georgia College Carollton, GA 30117 404/834-6835	
- A-95 Review/State Clearinghouse Clearinghouse		State Clearinghouse Office of Planning & Budget 270 Washington St., SW Atlanta, GA 30334 404/656-3804	
5. Geomorphology			
- Wetlands Identification	Fish and Wildlife Service	EPD, see Water Quality Standards Program	
- Geological Data	Geological Survey	EPA, see Water Quality Standards Program	
- Dredge & Fill Permits	Army Corps of Engineers	EPD, see Water Quality Standards Program	
6. Hydrology/Meteorology			
- Flow data	Geological Survey	EPD, see Water Quality Standards Program	
- Floodplain management	Federal Emergency Management Administration	EPD, see Water Quality Standards Program	APDC's[1] City/County Planning Depts.
- Groundwater data	Geological Survey	EPD, see Water Quality Standards Program	County Public Health Depts.
- Meteorologic data	National Weather Service		
7. Water Quality (See Nos. 1, 2 & 3)			
- Water Quality Data	Environmental Protection Agency Geological Survey Army Corps of Engineers	EPD, see Water Quality Standards Program	County Public Health Depts. Universities
8. Ecology			
- Protected Species	Fish and Wildlife Service	DNR, Fish & Game Division 270 Washington St., SW Atlanta, GA 30334 404/656-4713	
-Wildlife		DNR, Fish & Game Division 270 Washington St., SW Atlanta, GA 30334 404/656-4713	
- Rare or endangered Wetlands (see Section 2.)			
- Erosion and Sedimentation Control		EPD, See Water Quality Standards Program State	

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[1] See list of Georgia APDCs.

[1]Georgia Area Planning and Development Commissions

Altamaha Georgia Southern APDC
P.O. Box 328
Baxley, GA 31513

Central Savannah River APDC
P.O. Box 2800
Augusta, GA 30904
404/738-5337

Chattahoochee-Flint APDC
P.O. Box 1363
LaGrange, GA 30240
404/882-2956

Coastal APDC
P.O. Box 1316
Brunswick, GA 31520

Coastal Plan APDC
P.O. Box 1223
Valdosta, GA 31601
912/247-3494

Coosa Valley APDC
P.O. Drawer H
Rome, GA 30161
404/234-8507

Georgia Mountains APDC
P.O. Box 1720
Gainesville, GA 30501

Heart of Georgia APDC
101 Oak Street
Eastman, GA 31023
912/374-4771

Lower Chattahoochee APDC
P.O. Box 1908
Columbus, GA 31901
404/324-5221

Middle Flint APDC
P.O. Box 6
Ellaville, GA 31806
912/928-1204

McIntosh Trail APDC
P.O. Box 241
Griffin, GA 30223
404/227-3096

Middle Georgia APDC
711 Grand Building
Macon, GA 31201
912/743-5862

Northeast Georgia APDC
305 Research Drive
Athens, GA 30601
404/548-3141

Oconee APDC
P.O. Box 707
Milledgeville, GA 31061

Southeast Georgia APDC
P.O. Box 1276
Waycross, GA 31501
912/283-3931

Southwest Georgia APDC
P.O. Box 346
Camilla, GA 31730
912/336-5616

North Georgia APDC
212 Pentz Street
Dalton, GA 30720
404/226-1672

Table 9-36 Agency Responsibilities and Data Sources - KENTUCKY

Area of Jurisdiction	Federal	State	Regional/Local
1. Water Quality Standards Program	EPA Region IV	Dept. for Environmental Protection (DEP) Natural Resources and Environmental Protection Cabinet Division of Water Quality Fort Boone Plaza 18 Rielly Road Frankfurt, KY 40601 502/564-3410	
2. NPDES Permit Program	EPA Region IV	DEP, see Water Quality Standards Program	
3. Construction Grants Program	EPA Region IV	DEP, see Water Quality Standards Program	
4. Planning			
- Land use (general--population projections, development trends, etc.) development trends, etc.)			Regional Planning Units City/County Planning Depts.
- Archeological/Historical		Heritage Division 104 Bridge Street Frankfurt, KY 40601 502/564-6683	
- A-95 Review/State Clearinghouse		DEP, Office of Special Projects Capitol Plaza Tower Fourth Floor Frankfurt, KY 40601 502/564-7320	
5. Geomorphology			
- Wetlands Identification	Fish and Wildlife Service	DEP, see Water Quality Standards Program	
- Geological Data	Geological Survey	DEP, see Water Quality Standards Program	
- Dredge & Fill Permits	Army Corps of Engineers	DEP, Bureau of Surface Mining Reclamation and Enforcement Capitol Plaza Tower Sixth Floor Frankfurt, KY 40601 502/564-6940 502/564-6940	
6. Hydrology/Meteorology			
- Flow data	Geological Survey	DEP, see Water Quality Standards Program	
- Floodplain management	Federal Emergency Management Administration	DEP, Division of Water Quality Floodplain Management Section Fort Boone Plaza 18 Rielly Road Frankfurt, KY 40601 502/564-7085	Regional Planning Units City/County Planning Depts.
- Groundwater data	Geological Survey	DEP, see Water Quality Standards Program	County Public Health Depts.
- Meteorologic data	National Weather Service		
7. Water Quality (See Nos. 1, 2 & 3)			
- Water Quality Data	Environmental Protection Agency Geological Survey Army Corps of Engineers	DEP, see Water Quality Standards Program	Utilities County Public Health Depts. Universities
8. Ecology			
- Protected Species	Fish and Wildlife Service	Dept. of Fish and Wildlife Resources (DFWR) Arnold Mitchell Building #1 Game Farm Road Frankfurt, KY 40601 502/564-4406	
- Wildlife		DFWR, see Protected Species	
- Rare or endangered Wetlands (see Section 2,)			

Table 9-37 Agency Responsibilities and Data Sources - MISSISSIPPI

Area of Jurisdiction	Federal	State	Regional/Local
1. Water Quality Standards Program	EPA Region IV	Dept. of Natural Resources (DNR) Bureau of Pollution Control P.O. Box 10385 Jackson, MS 39209 601/961-5171	
2. NPDES Permit Program	EPA Region IV	DNR, see Water Quality Standards Program	
3. Construction Grants Program	EPA Region IV	DNR, see Water Quality Standards Program	
4. Planning			
- Land use (general--population projections, development trends, etc.)			City/County Planning Depts.
- Archeological/Historical		Department of Archives and History 100 State Street Jackson, MS 39205 601/354-6218	
- A-95 Review/State Clearinghouse		Dept. of Planning and Policy 1304 Walter Sillers Blvd 500 High Street Jackson, MS 39202 601/354-7018	
5. Geomorphology			
- Wetlands Identification	Fish and Wildlife Service	DNR, see Water Quality Standards Program	
- Geological Data	Geological Survey	DNR, Bureau of Geology P.O. Box 5348 Jackson, MS 39216 601/354-6228	
- Dredge & Fill Permits	Army Corps of Engineers	DNR, see Water Quality Standards Program	
6. Hydrology/Meteorology			
- Flow data	Geological Survey	DNR, Bureau of Land and Water Resources P.O. Box 10631 Jackson, MS 39209 601/961-5202	
- Floodplain management	Federal Emergency Management Administration	Mississippi Research and Development Center 3825 Ridgewood Road P.O. Drawer 2470 Jackson, MS 39205 601/982-6456	City/County Planning Depts.
- Groundwater data	Geological Survey	DNR, see Flow data	
- Meteorologic Data	National Weather Service		
7. Water Quality (See Nos. 1, 2 & 3)			
- Water Quality Data	Environmental Protection Agency	DNR, see Flow data	Utility authorities County Public Health Depts. Universities
	Geological Survey		
	Army Corps of Engineers		
8. Ecology			
- Protected Species	Fish and Wildlife Service	DNR, Bureau of Fisheries and Wildlife Game and Fish Commission P.O. Box 451 Jackson, MS 39205 601/961-5300	
- Wildlife		DNR, see Protected Species	
- Rare or Endangered Wetlands (see Section 2.)			
- Coastal Wetlands Protection Protection		Dept. of Wildlife Conservation Bureau of Marine Resources P.O. Drawer 959 ong Beach, MS 39560 01/864-4602 State	

Table 9-38 Agency Responsibilities and Data Sources - NORTH CAROLINA

Area of Jurisdiction	Federal	State	Regional/Local
1. Water Quality Standards Program	EPA Region IV	Department of Natural Resources and Community Development (DNRCD)[1] Division of Environmental Management (DEM) P.O. Box 27687 Raleigh, NC 27611 919/733-7120	
2. NPDES Permit Program	EPA Region IV	DNRCD, see Water Quality Standards Program	
3. Construction Grants Program	EPA Region IV	DNRCD, see Water Quality Standards Program	
4. Planning			
- Land use (general--population projections, development trends, etc.)			Regional Planning Councils[2] City/County Planning Depts.
- Archeological/Historical		Department of Administration Department of Cultural Resources State Historic Preservation Office	
- Easements over Water		Department of Administration State Property Office 116 West Jones Street Raleigh, NC 27611 919/733-4346	
- State Environmental Policy		Office of State Budget and Management (OSBM) 116 West Jones Street Raleigh, NC 27611 919/733-7061	
- State Clearinghouse		State Clearinghouse 116 West Jones Street Raleigh, NC 27611 OSBM, see State Environmental Policy	
5. Geomorphology			
- Wetlands Identification	Fish and Wildlife Service	DEM, see Water Quality Standards Program	
- Geological Data	Geological Survey	DNRCD, Division of Land Resources P.O. Box 27687 Raleigh, NC 27611 919/733-4574	
- Dredge & Fill Permits	Army Corps of Engineers	Office of Coastal Management P.O. Box 27687 Raleigh, NC 27611 919/733-2293	
- Sedimentation and Erosion Control		DNRCD, see Geological data	
6. Hydrology/Meteorology			
- Flow data	Geological Survey	DEM, see Water Quality Standards Program	
- Floodplain Management	Federal Emergency Management Admin.		City/County Planning Depts.
- Groundwater Data	Geological Survey	DEM, see Water Quality Standards Program	
- Meteorologic Data	National Weather Service	DEM, see Water Quality Standards Program	

Table 9-38 (Continued)

Area of Jurisdiction	Federal	State	Regional/Local
7. Water Quality (See Nos. 1, 2 & 3)			
- Water Quality Data	Environmental Protection Agency Geological Survey Army Corps of Engineers	DEM, see Water Quality	Utilities County Public Health Depts. Universities
8. Ecology			
- Protected Species	Fish and Wildlife Service	Wildlife Resources Commission (WRC) P.O. Box 27687 Raleigh, NC 27611 919/733-3391	
- Wildlife		WRC, see Protected Species	
- Rare or endangered Wetlands (see Section 2,)			
- Areas of Environmental Concern		DEM, see Water Quality Standards Program	
- Vector Control		Department of Human Resources Division of Health Services P.O. Box 2091 Raleigh, NC 27602 919/733-6407	

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[1] See list of DNRCD Regional Offices
[2] See list of Regional Planning Councils

[1] North Carolina Department of Natural Resources and Community Development Regional Offices

Winston-Salem Regional Office
8003 Silas Cr. Pkwy. Ext.
Winston-Salem, NC 27106
919/761-2351

Asheville Regional Office
Interchange Blvd.
159 Woodfin St.
Asheville, NC 28801
704/253-3341

Mooresville Regional Office
919 N. Main St.
Mooresville, NC 28115
704/663-1699

Fayetteville Regional Office
Wachovia Blvd.
Suite 714
Fayetteville, NC 28301
919/486-1541

Raleigh Regional Office
P.O. Box 27687
Raleigh, NC 27611
919/733-1214

Washington Regional Office
1502 N. Market St.
Washington, NC 27889
919/946-6481

Wilmington Regional Office
7625 Wrightsville Ave.
Wilmington, NC 28403
919/256-4161

Coastal Management Field Services
108 S. Water St.
Elizabeth City, NC 27909
919-338-0205

Coastal Management Field Services
1502 N. Market St.
Washington, NC 27889
919/946-6481

Coastal Management Field Services
7225 Wrightsville Ave.
Wilmington, NC 28403
919/256-4161

[2] North Carolina Planning and Development Commissions

Southwestern NC Planning
and Economic Development Commission
P O Box 850
Bryson City, NC 28713

Land-of-Sky Regional Council
25 Heritage Drive
Asheville, NC 28806 C 681

Isothermal Planning and Development
Commission
P O Box 841
Rutherfordton, NC 28139

Region D Council of Governments
P O Box 1820
Boone, NC 28607

Western Piedmont Council of Governments
30 Third Street, NW
Hickory, NC 28601

Centralina Council of Governments
P O Box 35008
Charlotte, NC 28235 C 518-A

Pee Dee Council of Governments
280 S. Liberty St.
Government Center
Winston-Salem, NC 27101

Triangle J Council of Governments
P O Box 12276
Research Triangle Park, NC 27709

Kerr-Tar Regional Council of
Governments
P O Box 709
H[illegible]son, NC 27536

Region N Council of Governments
P O Box 1529
Lumberton, NC 28358 C 431

Cape Fear Council of Governments
P O Box 1491
Wilmington, NC 28402 C 412

Neuse River Council of Governments
P O Box 1717
New Bern, NC 28560 C 134

Mid-East Commission
P O Drawer 1787
Washington, NC 27889 C 172

Albemarle Regional Planning
and Development Commission
P O Box 646
Hertford, NC 27944

Piedmont Triad Council of Governments
Four Seasons Offices
2120 Pinecroft Road
Greensboro, NC 27407 C 218

Region L Council of Governments
P O Drawer 2748
Rocky Mount, NC 27801 C 760

Table 9-39 Agency Responsibilities and Data Sources - SOUTH CAROLINA

Area of Jurisdiction	Federal	State	Regional/Local
1. Water Quality Standards Program	EPA Region IV	Dept. of Health and Environmental Control (DHEC) Bureau of Water Pollution Control 2600 Bull Street Columbia, SC 29201 803/758-3877	
2. NPDES Permit Program	EPA Region IV	DHEC, see Water Quality Standards Program	
3. Construction Grants Program	EPA Region IV	DHEC, see Water Quality Standards Program	
4. Planning			
- Land Use (general—population projections, development trends, etc.)			Regional Council of Governments[1] City/County Planning Depts.
- Archaeological/Historical		State Historic Preservation Officer Department of Archives & History P.O. Box 11669 Columbia, SC 29211 803/758-5816 State Archeologist Institute of Archeology University of South Carolina Columbia, SC 29208 803/777-8170	
- A-95 Review/State Clearinghouse		StateClearinghouse Office of the State Auditor P.O. Box 11333 Columbia, SC 29211 803/758-7707	
5. Geomorphology			
- Wetlands Identification	Fish and Wildlife Service	DHEC, see Water Quality Standards Program	
- Geological Data	Geological Survey	DHEC, see Water Quality Standards Program	
- Dredge & Fill Permits Permits	Army Corps of Engineers	Environmental Affairs Division Water Resources Commission (WRC) P.O. Box 4515 Columbia, SC 22904 803/758-2514	
6. Hydrology			
- Flow data	Geological Survey	DHEC, see Water Quality Standards Program	
- Floodplain Management	Federal Emergency Management Administration	WRC, see Dredge & Fill Permits	Regional Council of Governments[1] City/County Planning Depts.
- Groundwater data	Geological Survey	DHEC, see Water Quality Standards Program WRC, see Dredge & Fill Permits (Geology-Hydrology Division)	County Public Health Depts.
- Meteorologic data	National Weather Service		
- Public Land and Water Resource Usage		WRC, see Dredge & Fill Permits	
7. Water Quality (See Nos. 1, 2 & 3)			
- Water Quality Data	Environmental Protection Agency	DHEC, see Water Quality Standards Program	Regional Council of Governments[1] County Public Health Depts.
	Geological Survey	WRC, see Dredge & Fill Permits	
	Army Corps of Engineers		

Table 9-39 (Continued)

Area of Jurisdiction	Federal	State	Regional/Local
8. Ecology			
- Protected Species	Fish and Wildlife Service	Wildlife and Marine Resources Dept. (WMRD) P.O. Box 167 Columbia, SC 29202 803/758-0014	
- Wildlife		WMRD, see Protected Species	
- Rare or endangered Wetlands (see Section 2.)			
- Heritage Trust Program		WMRD, see Protected Species	
- Wild & Scenic Rivers Rivers		WRC, Planning Division P.O. Box 4515 Columbia, SC 29204 803/758-3754	

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[1]See list of Regional Council of Governments

[1] South Carolina Regional Councils of Government

South Carolina Appalachian Council
of Governments
Executive Director
Drawer 6668
Greenville, SC 29606

Upper Savannah Council of Governments
Executive Director
Box 1366
Greenwood, SC 29648

Catawba Regional Planning Council
Executive Director
Box 862
SCN Center, 100 Dave Lyle Blvd.
Rock Hill, SC 29730

Central Midlands Regional Planning
Council
Executive Director
Suite 155, Dutch Plaza
800 Dutch Square Blvd.
Columbia, SC 29210

Pee-Dee Regional Council of
Governments
Executive Director
Box 5719
Florence, SC 29502

Waccamaw Regional Planning and
Development Council
Executive Director
Box 419
Georgetown, SC 29440

Berkeley-Charleston-Dorchester
Council of Governments
Executive Director
Business and Technology Center
Suite 1-548
701 East Bay Street
Charleston, SC 29403

Lowcountry Council of Governments
Executive Director
P O Box 98
Yemassee, SC 29945

Lower Savannah Council of
Governments
Executive Director
Box 850
Aiken, SC 29801

Santee-Lynches Council for
Governments
Executive Director
Box 1837
Sumter, SC 29150

Table 9-40 Agency Responsibilities and Data Sources – TENNESSEE

Area of Jurisdiction	Federal	State	Regional/Local
1. Water Quality Standards Program	EPA Region IV	Department of Health and Environment (DHE) Division of Water Quality Control Terra Bldg. 150 9th Avenue, North Nashville, TN 37203 615/741-7883	
2. NPDES Permit Program	EPA Region IV	DHE, see Water Quality Standards Program	
3. Construction Grants Program	EPA Region IV	DHE, see Water Quality Standards Program	
4. Planning			
- Land use (general--population projections, development trends, etc.)		State Planning Office (TSPO) 1800 James K. Polk Bldg. 505 Deaderick St. Nashville, TN 37219 615/741-1676	Regional Planning Commissions[1] City/County Planning Depts.
- Archeological/Historical		Department of Conservation Division of Archeology 5103 Edmondson Pike Nashville, TN 37211 615/741-1588	
		Department of Conservation Historical Commission State Historic Preservation Office 4721 Trousdale Drive Nashville, TN 37219 615/741-2371	
- A-95 Review/State Clearinghouse		TSPO, see Land Use	
5. Geomorphology			
- Wetlands identification	Fish and Wildlife Service	DHE, see Water Quality Standards Program	
- Geological Data	Geological Survey	Department of Conservation Division of Surface Mining and Reclamation 1720 West End Ave. Nashville, TN 37203 615/741-3042	
- Dredge & Fill Permits	Army Corps of Engineers	DHE, see Water Quality Standards Program	
6. Hydrology/Meteorology			
- Flow data	Geological Survey	DHE, see Water Quality Standards Program	
- Floodplain management	Federal Emergency Management Administration	TSPO, see Land Use	
- Groundwater data	Geological Survey	Department of Conservation Division of Water Resources 4721 Trousdale Drive Nashville, TN 37219 615/741-6860	
- Meteorologic data	National Weather Service		
7. Water Quality (See Nos. 1, 2 & 3)			
- Water quality data	Environmental Protection Agency Geological Survey Army Corps of Engineers	DHE, see Water Quality Standards Program	Regional Planning Commissions[1] Utilities County Public Health Depts. Universities

Table 9-40 (Continued)

Area of Jurisdiction	Federal	State	Regional/Local
8. Ecology - Protected Species	Fish and Wildlife Service	Wildlife Resources Agency Ellington Agricultural Center P.O. Box 40747 Nashville, TN 37204 615/741-1517 (permitting and animals) Heritage Program Department of Conservation 2611 West End Ave. Nashville, TN 37203 615/741-3852 (Plants)	
- Wildlife		Wildlife Resources Agency, see Protected Species	
- Rare or Endangered Wetlands (see Section 2.)		State	

[1] See list of Regional Planning Commissions

[1] Tennessee Development Districts

METRO	NON-METRO
East Tennessee Development District Westwood Building 5616 Kingston Pike P O Box 19806 Knoxville, TN 37919	Northwest Tennessee Development District Director of Planning P O Box 63 Martin, TN 38237
First Tennessee-Virginia Development District 207 North Boone Street Johnson City, TN 37601	South Central Tennessee Development District 805 Nashville Highway P O Box 1346 Columbia, TN 38401
Memphis Delta Development District Director of Planning 160 North Main, Mid-America Mall Memphis, TN 38103	Southwest Tennessee Development District Director of Planning 416 East Lafayette St. Jackson, TN 38301
Mid-Cumberland Development District 501 Union Street, Suite L100 Nashville, TN 37219	Upper Cumberland Development District 1225 Burgess Falls Road Cookeville, TN 38501
Southeast Tennessee Development District	

Table 9-41. U.S. Environmental Protection Agency Program Contacts

Water Quality Standards Program	EPA Region IV Water Quality Section 345 Courtland St. Atlanta, GA 30365 404/881-3116
NPDES Permit Program	EPA Region IV Permits Section 345 Courtland St. Atlanta, GA 30365 404/881-3012
Construction Grants Program	
Northern Area (KY, NC, SC, TN)	EPA Region IV Grants Management Section 345 Courtland St. Atlanta, GA 30365 404/881-2005
Southern Area (AL, FL, GA, MS)	EPA Region IV Grants Management Section 345 Courtland St. Atlanta, GA 30365 404/881-3633

Table 9-42. U.S. Fish and Wildlife Service - Habitat Resources Field Offices

Region 4
U.S. Fish & Wildlife Service
Richard B. Russell Bldg.
75 Spring Street, S.W.
Atlanta, GA 30303

Ecological Services

U.S. Fish & Wildlife Service
Ecological Services
P O Drawer 1190
Daphne East Office Plaza
Highway 98
Daphne, AL 36526

U.S. Fish & Wildlife Service
Ecological Services
1612 June Ave.
Panama City, FL 32401

U.S. Fish & Wildlife Service
Ecological Services
P O Box 2676
Press-Journal Bldg.
1323 - 21st St.
Vero Beach, FL 32960

U.S. Fish & Wildlife Service
Ecological Services
Federal Bldg., Room 334
Brunswick, GA 31520

U.S. Fish & Wildlife Service
Ecological Services
Room 409, Merchants National Bank Bldg.
820 South St.
Vicksburg, MS 39180

U.S. Fish & Wildlife Service
Ecological Services
Room 468, Federal Bldg.
310 New Bern Ave.
Raleigh, NC 27601

U.S. Fish & Wildlife Service
Ecological Services
P O Box 12559
217 Ft. Johnson Rd.
Charleston, SC 29412

U.S. Fish & Wildlife Service
Ecological Services
P O Box 845
Cookeville, TN 38503

Endangered Species

U.S. Fish and Wildlife Service
Endangered Species
2747 Art Museum Drive
Jacksonville, FL 29

U.S. Fish and Witdlife Service
Endangered Species
Jackson Mall Office Center
300 Woodrow Wilson Ave.
Suite 3185
Jackson, MS 39215

U.S. Fish and Wildlife Service
Endangered Species
Plateau Building, Room A5
50 South French Broad Ave.
Asheville, NC 28801
704/259-0321

Table 9-43. U.S. Army Corps of Engineers Districts

Army Corps of Engineers (NC, TN)[1]
Nashville District
P O Box 1070
Nashville, TN 37202
615/749-5181

Army Corps of Engineers (NC)
Huntington District
P O Box 2127
Huntington, WV 25712
304/529-5487

Army Corps of Engineers (NC)
Norfolk District
803 Front St. - Fort Norfolk
Norfolk, VA 23510
804/441-3300

Army Corps of Engineers (NC)
Wilmington District
P O Box 1890
Wilmington, NC 28402
919/343-4511

Army Corps of Engineers (TN)
Memphis District
668 Clifford Davis Federal Building
Memphis, TN 38103
901/521-3168

Army Corps of Engineers (FL)
Jacksonville District
P O Box 4970
Jacksonville, FL 32232

Army Corps of Engineers (AL, FL)
Mobile District
P.O. Box 2288
Mobile, AL 36628-0001
205/690-2511

Army Corps of Engineers (SC)
Charleston District
P.O. Box 919
Charleston, SC 29402
803/577-4171

Army Corps of Engineers (GA)
Savannah District
P.O. Box 889
Savannah, GA 31402
912/233-8822

Army Corps of Engineers (KY)
Louisville District
P.O. Box 59
Louisville, KY 40201
502/582-5601

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[1] Indicates states included in district offices' jurisdiction.

Table 9-44 State Conservationists

State Soil Conservation Service
665 Opelika Road
P O Box 311
Auburn, AL 36830

State Soil Conservation Service
Federal Building, Room 248
401 S.E. 1st Ave.
Gainesville, FL 32601

State Soil Conservation Service
Federal Building
355 E. Hancock Avenue
P O Box 832
Athens, GA 30613

State Soil Conservation Service
333 Waller Avenue, Room 305
Lexington, KY 40504

State Soil Conservation Service
Federal Bldg., Suite 1321
100 West Capitol Street
Jackson, MS 39269

State Soil Conservation Service
Federal Office Bldg., Rm. 535
310 New Bern Ave.
Raleigh, NC 27601

State Soil Conservation Service
1835 Assembly St., Room 950
Strom Thurmond Federal Bldg.
Columbia, SC 29201

State Soil Conservation Service
U.S. Courthouse, Rm. 675
801 Broadway Street
Nashville, TN 37203

Table 9-45. U.S. Geological Survey, District Offices - Southeastern Region

U.S. Geological Survey
Regional Office, Water Resources Division
75 Spring Street, SW
Atlanta, GA 30303

U.S. Geological Survey
District Office
520 19th Avenue
Tuscaloosa, AL 35401

U.S. Geological Survey
District Office
227 N. Bronough St., Suite 3015
Tallahassee, FL 32301

U.S. Geological Survey
District Office
6481 Peachtree Industrial Blvd.
Suite B
Doraville, GA 30360

U.S. Geological Survey
District Office
Room 572, Federal Building
600 Federal Place
Louisville, KY 40202

U.S. Geological Survey
District Office
Suite 710, Federal Building
100 West Capitol Street
Jackson, MS 39269

U.S. Geological Survey
District Office
P.O. Box 3857
Room 436, Century Station
300 Fayetteville St. Mall
Raleigh, NC 27602

U.S. Geological Survey
District Office
Strom Thurmond Federal Bldg.
Suite 658, 1835 Assembly Street
Columbia, SC 29201

U.S. Geological Survey
District Office
A413 Federal Building
U.S. Courthouse
Nashville, TN 37203r

Table 9-46 State Natural Heritage Programs

Eastern Regional Heritage Program
The Nature Conservancy
294 Washington St.
Boston, MA 02108
617/542-1908

Alabama Natural Areas Inventory
Natural Resources Center
P O Box 6282
University of Alabama
Tuscaloosa, AL 35486
205/348-4520

Florida Natural Areas Inventory
254 E. 6th Avenue
Tallahassee, FL 32303
904/224-8207

Kentucky Heritage Program
KY Nature Preserves Commission
407 Broadway
Frankfort, KY 40601
502/564-2886

Mississippi Natural Heritage Program
111 N. Jefferson St.
Jackson, MS 39202
601/254-7226

North Carolina Natural Heritage
Dept. of Natural & Economic Res.
Div. of State Parks
P O Box 27687
Raleigh, NC 27611
919/733-7795

South Carolina Heritage Trust
SC Wildlife & Marine Resources Dept.
P O Box 167
Columbia, SC 29202
803/758-0014

Tennessee Natural Heritage Program
Ecological Services
Department of Conservation
701 Broadway
Nashville, TN 37203
615/742-6545

TVA Regional Heritage
Office of Natural Resources
Norris, TN 37838

Table 9-47. Common Data Sources.

1. Topographic Maps - USGS
2. County Highway Maps - DOT, City/County/Regional Planning Commissions
3. Wetlands Maps - USGS, USFWS
4. Soils Information & Maps - SCS
5. Wetland Ownership/Availability -
    Regional Planning Councils
    City/County Planning Depts.
    City/County Tax Records Offices
6. Water Quality Data - USGS

    Storet - EPA

REFERENCES

In addition to literature referenced below, two bibliographies have been published on the use of wetlands for wastewater management. These are a valuable resource for those involved in wetlands management. The first document was jointly published by the U.S. EPA and U.S. Fish and Wildlife Service in 1984 entitled "The Ecological Impacts of Wastewater on Wetlands--An Annotated Bibliography" (EPA 905/3-84-002). The second document was recently made available by the Center for Wetlands Resources, Louisiana State University, Baton Rouge, Louisiana.

Preface

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U.S. Environmental Protection Agency. 1984. Saltwater wetlands for wastewater management environmental assessment. EPA Region IV, Atlanta, GA. EPA 904/10-84-128.

Chapter 2

Cowardin, L., V. Carter, F. Golet and E. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Dept. Interior, Fish and Wildlife Serv., Office of Biol. Serv., Washington, DC. #FWS/OBS-79/31.

Day, J. W. 1981. Personal communication. Center for Wetlands, Louisiana State University, Baton Rouge, LA.

Hefner, J. M. and J. D. Brown. 1984. Wetland trends in the southeastern United States. J. Soc. Wetland Scientists. 4:1-11.

Office of Technology Assessment. 1984. Wetlands: their use and regulation. U.S. Congress, Washington, DC OTA-0-206.

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U.S. Fish and Wildlife Service. 1984. Wetlands of the Untied States: current status and recent trends. U.S. FWS, Newton Corner, MA.

U.S. Fish and Wildlife Service. 1984b. Southeast regional resource plan. U.S. FWS, Atlanta, GA.

Chapter 3

Cowardin, L., V. Carter, F. Golet and E. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Dept. Interior, Fish and Wildlife Serv., Office of Biol. Serv., Washington, DC. #FWS/OBS-79/31.

Nichols, D. S. 1983. Capacity of natural wetlands to remove nutrients from wastewater. J. WPCF, 55(5):495-505.

U.S. Environmental Protection Agency. 1980. Consolidated permit regulations--40 CFR 122. Federal Register 45(98), May 19, 1980 and 45(141) July 21, 1980.

U.S. Environmental Protection Agency. 1983. Water quality standards regulations--40 CFR 35, 120 and 131. Federal Register 48(217), November 8, 1983.

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Chapter 4

Adamus, P. R. and L. T. Stockwell. 1983. A method for wetland functional assessment: Volumes 1 and 2. U.S. Department of Transportation, FHWA, Washington, DC. FHWA-IP-82-23.

Brown, M. T., and E. M. Starnes. 1983. A wetlands study of Seminole County. Center for Wetlands, Univ. Florida. Technical Report 41.

Canada/Ontario Steering Committee on Wetland Evaluation. 1983. An evaluation system for wetlands of Ontario south of the Precambrian Shield. First Edition. Ontario Ministry of Natural Resources and Canadian Wildlife Service.

Cowardin, L., V. Carter, F. Golet and E. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Dept. Interior, Fish and Wildlife Serv., Office of Biol. Serv., Washington, DC. #FWS/OBS-79/31.

Henderson, T. R., W. Smith and D. G. Burke. 1983. Non-tidal wetlands protection: a handbook for Maryland local governments. Maryland Dept. of Natural Resources.

Hyde, H. C., R. S. Ross and F. Dengen. 1982. Technology assessment of wetlands for municipal wastewater treatment. Municipal Env. Res. Lab., EPA, Cincinnati, OH.

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McCormick, J. S. and H. A. Somes, Jr. 1982. The coastal wetlands of Maryland. Maryland Department of Natural Resources.

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Nichols, D. S. 1985. Capacity of natural wetlands to remove nutrients from wastewater. J. WPCF, 55(5):495-505.

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Hammer, D. E. and R. H. Kadlec. 1983. Design principles for wetland treatment systems. U.S. Environmental Protection Agency. Robert S. Kerr Environmental Research Laboratory, Ada, OK. EPA 600/2-83-026.

Hopkinson, C. S., Jr. and J. W. Day. 1980. Modelling hydrology and eutrophication in a Louisiana Swamp Forest Ecosystem. Environ. Manage. 4:325-335.

Hyde, H. C., R. S. Ross and F. Demegen. 1982. Technology assessment of wetlands for municipal wastewater treatment. U.S. Environmental Protection Agency. Municipal Environmental Research Laboratory. Cincinnati, OH.

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Chapter 6

Adams, L. W. and L. E. Dove. 1984. Urban wetlands for stormwater control and wildlife enhancement. National Institute for Urban Wildlife, Columbia, MD.

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